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Handling Waterhammer

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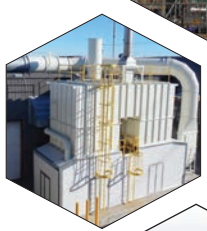
Cover Story

In the News



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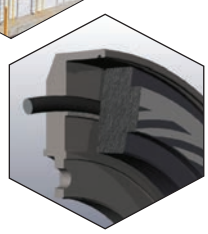

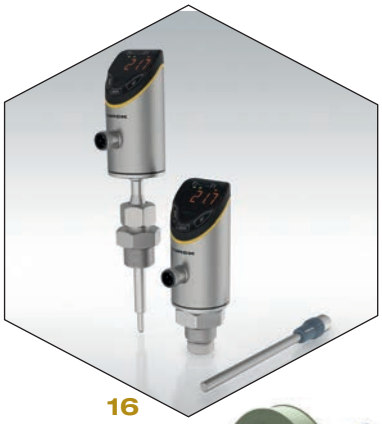

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Coming in April

Look for: **Feature Reports** on Filtration; and Expanders; A **Focus** on Analyzers; A **Facts at your Fingertips** on Corrosion; a **Newsfront** on Plant Security; A **Solids Processing** article on Solids Drying; **New Products**; and much more

Cover design: Tara Bekman

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Editor's Page

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Calling all experts

Do your colleagues often come to you with questions about a particular topic? Do you find yourself assigned to certain types of projects? Do others seek career advice from you? These are all signals that you are an expert in your field, and others can benefit by learning from your knowledge and experience.

Engineers are often multi-taskers and may hold a variety of jobs during their careers. Often, our jobs require us to gain expertise in certain areas — maybe it is in emulsions, or centrifugation, distillation, drying, high-purity handling techniques, solids handling, filtration, troubleshooting pump problems, valve selection, heat transfer, bioprocessing, emissions control, safety, cost estimating, simulation, control systems and so on. Your expertise can be very valuable to others. Experienced engineers may need to take a deeper dive into topics that they have not yet encountered in their own careers. And engineers who are just starting their careers need to learn the practical aspects of their jobs to help them broaden their knowledge base and be better able to contribute to the team.

One way to share your expertise with a broad audience is to write an article for publication. *Chemical Engineering* seeks manuscripts written by experts in the field to serve our readers. If you might be interested in writing such an article, we would like to hear from you.

What we look for

Chemical Engineering is edited for "technical decision-makers" — persons who apply their engineering training to make technical and business decisions. Our readers include chemical engineers, chemists and other engineers and scientists who work in production, design, construction, research and development or technical management. Our readers look for practical information that can be used directly on the job, as well as the latest news affecting the chemical process industries. The main thing we look for in outside-authored articles is therefore, practical information written by experts. And we seek original articles that have not been published elsewhere.

Our articles cover a wide variety of topics that range from highly technical to the "soft skills" needed by engineers in their technical development. If you are interested in writing an article for possible publication, we encourage you to reach out to us with an abstract of what you would like to write about. Our editors can help you with any questions you may have.

Inside this issue

This month's Cover Story addresses waterhammer, describing what it is and offering guidance on how to mitigate potential problems. Our first Feature Report describes seals for caustic service, while the second Feature Report tackles some of the common problems that can occur with polymeric and elastomeric materials and offers a pictorial guide to these issues. Crystallization is the focus of our Newsfront, which explores how industrial applications are looking to this unit operation to help advance sustainability-related goals. We also have sections on thermal oxidizers, sensors, new products and the latest technical and business news. We hope you enjoy reading. ■

Dorothy Lozowski, Editorial Director

Edited by:
Gerald Ondrey

ADHESIVES

Researchers at Oak Ridge National Laboratory (Oak Ridge, Tenn.; www.ornl.gov) developed a series of autonomous self-healable and highly adhesive elastomers that are fabricated via a simple, efficient and scalable process. The self-healing elastomers demonstrated unprecedented adhesion strength and the ability to adhere to many surfaces, which could broaden their potential use in industrial applications.

In a recent study published in *Advanced Functional Materials*, ORNL researchers used a blend of a self-healing polymer with curable elastomers to produce a series of self-healable and highly adhesive materials. The team proved that these elastomers can self-repair in ambient temperatures and conditions, as well as underwater, with their adhesive force only minimally impacted by surface dust. "These tough elastomers can be made simply and efficiently through a scalable process, enabling a wider range of uses for the building, automotive and electronics industries," ORNL's Diana Hun says.

MEMBRANE

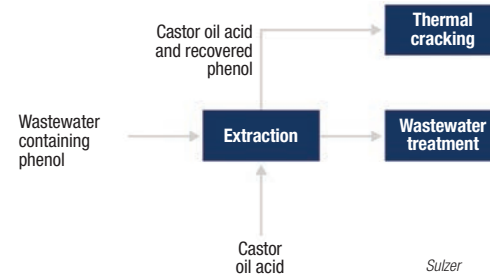
Professor Matsuyama Hideto's research group at Kobe University's (Japan; www.kobe-u.ac.jp) Research Center for Membrane and Film Technology has developed a new, ultrathin desalination membrane that rejects 95% of sodium chloride permeation. The membrane is made by laminating graphene-oxide nanosheets onto the surface of a porous polymer membrane. The graphene oxide is chemically reduced with L-ascorbic acid and am-

(Continues on p. 6)

LLE technology closes the loop on phenol removal

Many industrial processes involve phenol, but its toxic nature means that it must be effectively removed from waste streams prior to any subsequent biological treatment steps. Phenol can be removed via evaporation, but this method is quite energy-intensive. Alternatively, the phenol content may be transformed into phenolates for removal, but this process requires a number of intermediate steps that increase costs.

Sulzer Chemtech Ltd. (Winterthur, Switzerland; www.sulzer.com) recently unveiled a solvent-based liquid-liquid extraction (LLE) process for treating phenol-laden wastewater from sebacic acid production (diagram). In the manufacture of sebacic acid, castor oil is hydrolyzed to form ricinoleic acid, which undergoes an alkali fusion-cracking step in the presence of phenol and sodium hydroxide, resulting in a phenol-rich wastewater stream. Employing Sulzer's ECR agitated column in the LLE scheme, the process removes phenol using ricinoleic acid, which is already used as a reagent to form sebacic acid, thus eliminating the need for additional solvents, as well as solvent-recovery systems. Furthermore, the phenol extracted from the wastewater is reutilized in the alkali fusion-cracking stages of the process, reducing the demand for "virgin" phenol. This creates a closed-loop, circular system, where both ricinoleic acid and



Sulzer

phenol re-enter the process flow. This technology marks the first commercial application of ECR columns for LLE of phenol from wastewater using ricinoleic acid.

In a commercial-scale installation, the system has demonstrated that it can reduce the concentration of phenol in wastewater from 1,000 down to 200 parts per million (ppm). Sulzer says that its ECR system provides efficiencies for LLE because the column can fit an elevated number of theoretical stages into a limited equipment footprint. Also, since the ECR does not rely on mixer-settlers as in typical LLE installations, the need for ancillary equipment is eliminated and energy consumption is reduced. Additionally, the ECR column avoids the creation of emulsions, which can form in the presence of mixer-settlers and create challenges in phase separation. Instead, explains Sulzer, the ECR creates small droplets in a controlled manner to optimize mass transfer and phase separation.

A two-step process reduces N_2O emissions

Last month, Lanxess AG (Cologne, Germany; www.lanxess.com) inaugurated a new plant in Lillo/Antwerp, Belgium to reduce the nitrous oxide emissions that are generated during the production of caprolactam. The €10-million investment breaks down approximately 500 metric tons (m.t.) of N_2O per year, which is equivalent to the climate impact of 150,000 m.t./yr of CO_2 (CO_2e). A second plant to reduce an additional 300,000 m.t./yr of CO_2e is planned to start up in 2023.

The new plant uses a two-step process that was developed with cooperation partner CTP Chemisch Thermische Prozesstechnik GmbH (CTP; Graz, Austria; https://ctp-airpollutioncontrol.com). In the first step, N_2O is broken down into N_2 and O_2 using a regenerative thermal oxidation (RTO) process at 1,000°C. In the second step, the oxides of nitrogen (NOx) are reacted with ammonia in a selective catalytic reduction (SCR) unit operating at 250–450°C to produce N_2 and water. The combination has an overall 90% abatement efficiency.

The plant has a high thermal efficiency, thanks to the use of a specially developed ceramic heat exchanger for heat integration. These heat exchangers capture and store the heat used in the thermal oxidation process and generated during the breakdown of N_2O and NOx. When the heat exchangers have stored the heat from the clean gas, the process flow changes direction and the heat exchangers now preheat the incoming exhaust gas. This change of direction then takes place recurrently. This means that significantly less external energy has to be supplied to keep the process running, says the company.

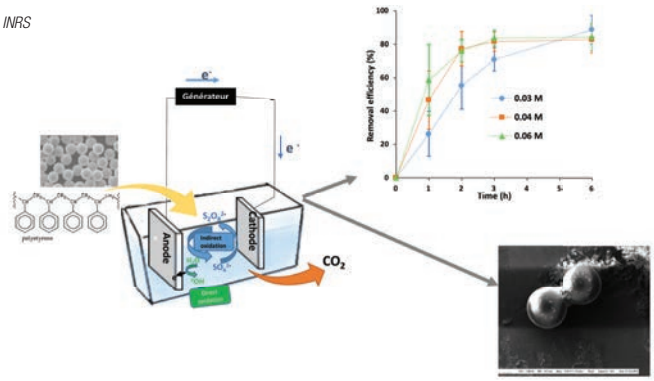
In addition to the Antwerp plant, the Group is currently implementing further climate-protection projects with the aim of becoming climate neutral by 2040.

Direct degradation of microplastics in wastewater

Microplastic pollutants in wastewater are notoriously difficult to treat, and can stem from many common sources, ranging from personal-care products to textiles. A new treatment technology developed by a team of researchers from Institut National de la Recherche Scientifique (INRS; Québec City, Canada; www.inrs.ca) led by professor Patrick Drogui aims to eliminate microplastic pollutants using electrocatalytic oxidation (diagram) at ambient temperature and pressure, effectively degrading microplastics. "Electricity is used to activate specific electrodes that produce, in situ, powerful oxidants that are required for microplastic degradation," explains Drogui, emphasizing that the process does not necessarily require the addition of chemicals. Conventional treatment approaches that tackle microplastics in wastewater involve physical separation techniques without actually degrading them, meaning that further downstream processing is required. "Another advantage of this process is that it is a 'zero-waste' technology, and microplastics are converted into water and CO_2, thus preventing the generation of toxic byproducts," adds Drogui.

The team analyzed the performance of three electrodes: boron-doped diamond, mixed metal oxide and iridium oxide. "We found that the boron-doped diamond electrode could degrade around 90% of the microplastics in water," notes Drogui. Furthermore, the strength of the electrocatalytic process indicates that it also works well in the presence of other contaminants. "We analyzed the performance of our process in the degradation of other contaminants present in wastewater and found that it was also effective in degrading other contaminants, including pharmaceutical compounds and detergents," he adds. The team has completed a proof-of-concept using synthetic effluent, and the next step will be to conduct trials using wastewater coming from a commercial laundry facility, where microplastics are released into water while washing fleece garments. Following these trials, the team hopes to demonstrate the technology in a pilot-scale installation at the outlet of a commercial laundry facility. Degrading the microplastics from wastewater directly at their source of origin (such as a commercial laundry facility) could greatly decrease the processing load on the downstream treatment plants.

INRS



monia to impart strengthened π-π interaction. By applying nanosheet coatings with intercalation of porphyrin-based planar molecules (with charged groups and a conjugated π system) to the surface of a porous membrane, the research group was able to construct an ultrathin (50 nm) desalination membrane layer. This layer demonstrated high ion-blocking functionality because the size of the nanochannels could be controlled within 1 nm.

The study was published recently in the *Journal of Materials Chemistry A.*

ENERGY HARVESTING

Scientists of Karlsruhe Institute of Technology (KIT; Germany; www.kit.edu) have developed three-dimensional component architectures for thermoelectric generators (TEGs) based on novel, printable thermoelectric materials. The results are reported in *npj Flexible Electronics* and *ACS Energy Letters*.

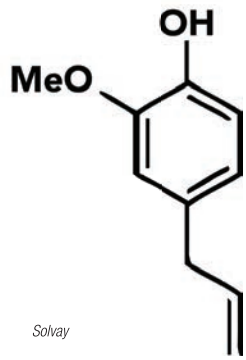
TEGs directly convert thermal into electrical energy. "This technology enables operation of autonomous sensors for the internet of things (IoT) or in wearables, such as smart watches, fitness trackers or digital glasses without batteries," says professor Uli Lemmer, head of the Light Technology Institute of KIT. In addition, they might be used for the recovery of waste heat in industry and heating systems or in the geothermal energy sector.

"Conventional TEGs have to be assembled from individual components using relatively complex manufacturing methods," Lemmer says. "To avoid this, we studied novel printable materials and developed two innovative processes and inks based on organic, as well as on inorganic nanoparticles." These processes and inks can be used to produce inexpensive, three-dimensional printed TEGs.

The first process uses screen printing to apply a 2-D pattern onto an ultrathin flexible substrate foil using thermoelectric printing inks. Then, a generator about the size of a sugar cube is folded by means of an origami technique. This method has been developed jointly by KIT researchers, the Heidelberg In-

(Continues on p. 8)

New process for synthetic eugenol available to fragrance market



Solvay

Solvay S.A. (Brussels, Belgium; www.solvay.com) recently announced a new commercial process for synthetic eugenol (diagram), a derivative of phenol, whose natural version is extracted from clove oil obtained from dried flower buds of clove trees grown in Indonesia and Madagascar. Synthetic eugenol offers a cost-effective alternative supply of the compound for applications that do not specifically require natural origins, and also offers protection from price volatility of natural clove oil for fragrance formulators.

As Corinne Duffy, the eugenol project manager at Solvay Aroma Performance, explains, the synthetic route for eugenol was first imagined by scientists at Solvay affiliate Rhône-Poulenc in the early 2000s, but the process never progressed beyond the pilot stage because the purification is very challenging, rendering the process economically unattractive. In the past two years, Solvay scientists, driven by strong demand for eugenol, revisited the process, focused on increasing yields and improving the separation stage.

The resulting process begins with phenol, which is converted into catechol, and then, from that, into the intermediate guaiacol. "Guaiacol is a key product in our chain, as it can be used for many applications," Duffy says. These applications include using guaiacol as an intermediate in the production of the flavor molecule vanillin and the cough suppressant guaifenesin, as well as the main raw material for the production of eugenol. The synthetic eugenol process features a carefully designed distillation stage to separate the desired end-product (*para*-eugenol) from the various co-products and byproducts with similar boiling points that result from the reaction of guaiacol to eugenol, Duffy explains.

Synthetic eugenol is now available to the fragrance market, Duffy says, but in the near future, the product could be incorporated into oral care products (toothpaste and mouthwash) for its antiseptic properties, once the company secures the necessary certifications.

Separate xylene isomers with less energy

Xylene isomers are usually derived from the catalytic reforming of crude oil, and require costly methods to separate them from each other, including distillation, fractional crystallization and adsorption in high-temperature and high-pressure environments. "The separation of xylene's isomers requires much energy and is a difficult process due to the isomers' overlapping physiochemical properties," says Abdul-Hamid Emwas, staff scientist in nuclear magnetic resonance (NMR) from the Imaging and Characterization Core Lab (IAC) at the King Abdullah University of Science and Technology (KAUST; Thuwal, Saudi Arabia; www.kaust.edu.sa). "These include identical molecular weights, close boiling points and similar structures."

KAUST associate professor Niveen Khashab and her research group recently teamed up with IAC and an international group of scientists to find a new and less energy-consuming method to separate and purify the isomers for the petrochemical industry. Their work is described in a recent issue of the journal *Chem*.

To separate the isomers, the research team took advantage of the properties of cucurbiturils, which are organic macrocyclic molecules made of glycoluril monomers linked by methylene bridges. They are shaped like pumpkins, with their hydrophobic central cavity able to hold smaller molecules.

The researchers used an aqueous solution of cucurbit[7]uril (or CB7), which "has strong and distinctive binding affinity with xylene isomers in water," says Gengwu Zhang, a postdoctoral fellow and the lead author of the paper. "Using liquid-liquid extraction (at room temperature and pressure), we showed that the hole in the middle of CB7 can selectively host *o*-xylene from mixtures of xylene isomers," explains Zhang. "We could separate *o*-xylene with selectivity of more than 92% after one extraction cycle."

Because the three isomers have different NMR spectra, NMR was used to perform the study: high-resolution 1-D NMR was used for quantitative analyses, and advanced 2-D NMR experiments were used to probe the separation mechanism that explains the novelty of the separation process using CB7.

The researchers showed that CB7 can separate xylenes from commercial oil samples at scales of up to 0.5 L. Also, laboratory scale-up experiments using commercial xylenes and C8 aromatic fraction of pyrolysis gasoline proved that CB7 is able to separate *o*-xylene with a selectivity of up to 83%.

novation Lab, and a spinoff of KIT. The second process consists of printing a 3-D scaffold onto the surfaces of which the thermoelectric ink is applied. Work is underway to commercialize the printed thermoelectric system.

STRONGER COMPOSITES

Ceramic matrix composites (CMCs) are incredibly strong materials used in jet engines, gas turbines and cutting tools for nickel superalloys. Aluminum oxide is hard and chemically inert, and tungsten carbide is used as a superhard material, but past efforts to create an Al_2O_3-WC CMC yielded unsatisfactory results. Recently, a study by Japanese scientists, published in *Scientific Reports*, shows that adding zirconium atoms results in improved Al_2O_3-WC CMCs.

Previously, no group had developed an Al_2O_3-WC CMC with a bending strength greater than 1 gigapascal (GPa), which meant that those earlier Al_2O_3-WC CMCs could not outperform the existing CMC materials. In an attempt to achieve a greater bending strength, a team led by scientists from Nagoya University (www.nagoya-u.jp), in collaboration with NGK Spark Plug Co. (both Nagoya, Japan), found that adding in small amounts of zirconium dioxide (ZrO_2) during the creation of Al_2O_3-WC CMCs yielded "superhard" Al_2O_3-WC CMCs with bending strengths greater than 2 GPa. Notably, the investigators achieved these considerable bending strength improvements with a relatively modest addition of ZrO_2. The additive represented less than 5% of the mass of the finished Al_2O_3-WC CMCs, which is less than the amount of additive usually present in additive-enhanced CMCs. Atomic-resolution scanning transmission electron microscopy revealed that the Zr atoms were located in thin layers between sheets of Al_2O_3 and WC, adding strength to the interfaces, which are generally weak points in the composites.

STRONGER POLYMERS

Toray Industries, Inc. (Tokyo, Japan; www.toray.com) has created a new polymer that retains the outstanding thermal resistance, rigidity and strength of polyamide 6 (PA6), while having a bending-fatigue limit that is 15 times that of

(Continues on p. 9)

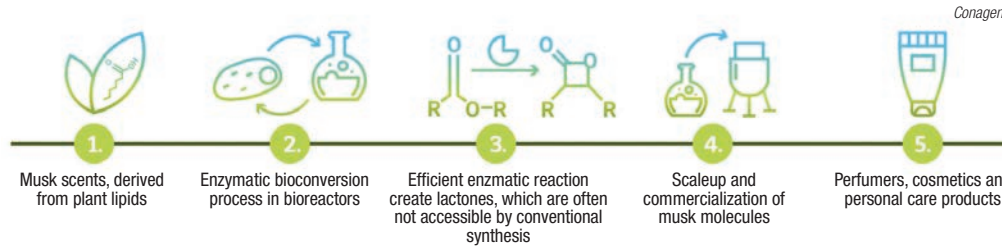
Sustainable enzyme-based production of macrocyclic lactones for fragrances

Planned commercial-scale production of macrocyclic gamma-lactone molecules using an enzymatic process will supply the flavors and fragrances market with sustainable alternatives to existing processes based on synthesizing petroleum-derived molecules or isolating molecules from natural sources.

The synthetic biology company Conagen Inc. (Bedford, Mass.; www.conagen.com) recently announced the commercial development of natural musk-scent compounds based on lactone (cyclic ester) chemistry for inclusion in scented formulations of colognes, perfumes, cosmetics, personal care products, household cleaners, air-care products and candles. The company says it plans to have its initial commercial product available to cosmetics customers through commercial partner Blue California, by mid-2021. The company anticipates additional compounds will enter commercial production in the subsequent months.

The commercial-scale process for producing the macrocyclic lactones is based on proprietary synthetic biology and metabolic engineering platform technologies developed by Conagen. In the case of musk scents, plant-derived lipids are converted into desired lactones using enzymatic conversion in bioreactors. "We have become very effective at maximizing the efficiency of the enzymatic reactions," explains Casey Lippmeier, vice president of innovation at Conagen, "and we specialize in scaling up processes from microliter volumes to tons." In addition to a more sustainable route to desired molecules, the platform technology allows the production of molecular structures that are not accessible with conventional industrial synthesis.

The company has more than 14 different microorganisms that it uses for microbial strain development. From there, Conagen scientists engineer new metabolic pathways and fermentation processes for a target molecule. Along with sustainable ingredients for the flavors and fragrances market, Conagen is using its platform technologies to develop compounds for nutritional supplements, food ingredients, specialty chemicals and others.



Modular NGL recovery

Honeywell UOP (Des Plaines, Ill.; www.uop.com) has adapted its recycle-split-vapor (RSV) technology for natural-gas liquid (NGL) recovery into a new, modular offering, RSV2, which enables quick retrofitting of existing gas-processing plants with minimal downtime. "The RSV2 technology can increase ethane recovery up to greater than 99%," explains John Wilkinson, general manager of UOP's Ortloff Engineers division. "In addition, when operating in full ethane-rejection mode, the technology can increase propane recovery up to greater to than 99%."

The RSV2 technology functions by recycling, cooling and condensing a high-purity product stream, providing a new reflux stream to an extension of the existing column, which enables both higher-purity products, as well as increased capacity through the gas-processing plant, adds Wilkinson. The RSV2 technology owes its recovery effectiveness to its ability to overcome the equilibrium limitations of existing gas-subcooled process (GSP) designs by providing a leaner reflux stream to the column, in both the recovery and rejection modes of operation. Honeywell UOP will install its first RSV2 units for Brazos Midstream (Fort Worth, Tex.; www.brazosmidstream.com), which will see the company upgrading two 200-million-ft^3/d cryogenic gas-processing plants in the Texas Permian Basin. For this project, UOP expects that its technology will improve upon the traditional GSP techniques by increasing NGL recovery rates from 92 to nearly 100%, leading to significantly better operating margins, says David Dickinson, leader of UOP's Midstream business.

Anaerobic fermentation process using human gut microfauna

Industrial-scale production of protein-rich food additives based on anaerobic fermentation is slated to begin later this year at a former bioethanol site in Minnesota. The facility will use a fermentation process developed by White Dog Labs (WDL; Newark, Del.; www.whitedoglabs.com) that involves microbial species found in the human gut microbiome.

The company employs a set of bacterial screening approaches designed to select not only for the production of specific metabolites, but also simultaneously for cell composition — specifically for high protein concentration. The anaerobic fermentation of sugars at the Minnesota site will be operated to produce protein-rich biomass that will be used as additives for human food and animal feed. Variations of the process can also produce metabolites (such as vitamins and short-chain fatty acids like butyrate and acetate) from sugars, and can be set up for gas fermentation.

"Current fermentation processes harvest metabolites generated by microbes, but we are also simultaneously maximizing the value of the biomass," says Bryan Tracy, CEO of WDL. This is done by focusing on microbes capable of producing high levels of protein and then using the microbes themselves as a protein source with a desirable amino acid profile, Tracy explains.

"We have an array of bacterial selection approaches that can 'tweeze out' microbiome-derived bacteria species that have the properties that we are looking for, including fast growth rate, metabolite production and amino acid profile, and also those that could not be grown under standard laboratory conditions," Tracy adds.

The company is targeting microbe strains from the human microbiome that would not ordinarily grow under standard laboratory conditions. "We are mimicking more closely the native gut microbiome environment to expand populations of species you wouldn't find in the laboratory, including the gut microbiome of humans, chickens, cow and others," Tracy says.

An advantage of anaerobic (without oxygen) fermentation processes is that the management of oxygen content is not necessary, so larger fermentation tanks can be used because you don't have to worry about introducing O_2, Tracy notes. ■

conventional polymers. Prospective applications for such durability include automobiles, appliances and sporting goods.

Toray focused on polyrotaxane — a supramolecular polymer with a beaded or necklace-like structure, its molecules consisting of strings and rings — which has a sliding molecular bond, as a polymer whose structure moves in response to external forces. The company endeavored to balance the inherent attributes of PA6 and fatigue resistance by finely dispersing polyrotaxane in the resin.

Toray used its proprietary Nanoalloy microstructure-control technology to maximize the effectiveness of polyrotaxane by dispersing it in the 10-nm crystals of PA6. The resulting flexible stress-dispersion mechanism led to the creation of the new polymer. ❐

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Plant Watch

Austria's largest green-hydrogen plant being constructed at OMV refinery

February 16, 2021 — OMV AG (Vienna, Austria; www.omv.com) and infrastructure bank Kommunalkredit Austria AG announced a joint €25-million investment in the construction of Austria's largest electrolysis plant at OMV's Schwechat petroleum refinery. The 10-MW electrolysis unit will produce up to 1,500 metric tons per year (m.t./yr) of green hydrogen once the plant starts up in 2023. The green hydrogen will be used for the hydrogenation of fuels.

Encina and Flint Hills Resources plan waste-plastic-based fuels and chemicals

February 16, 2021 — Encina Development Group, LLC (The Woodlands, Tex.; www.encina.com.) signed a non-binding term sheet with Flint Hills Resources, LLC (Wichita, Kan.; www.fhr.com) to produce renewable chemicals and renewable fuels from waste plastic. The parties may enter into a definitive agreement that includes building a renewable chemicals and fuels plant to process waste-plastic feedstock in Corpus Christi, Texas. Flint Hills Resources will market the renewable aromatic products produced at the Encina Corpus Christi facility, as well as work with its affiliates to market renewable aromatic products from other Encina sites around the U.S.

Air Products starts up cryogenic nitrogen plant in Malaysia

February 12, 2021 — Air Products (Lehigh Valley, Pa.) has brought onstream its first cryogenic nitrogen plant in the Bayan Lepas Free Industrial Zone in Penang, Northern Malaysia. The new facility further expands the company's capacity to supply the electrical and electronics sectors, as well as other manufacturing industries.

Evonik adds lipid production capacity to supply BioNTech vaccine manufacture

February 11, 2021 — Evonik Industries AG (Essen, Germany; www.evonik.com) is investing in a short-term production expansion for its specialty lipids, which are essential for mRNA-based COVID-19 vaccines. Commercial lipid quantities are to be produced at Evonik's Hanau and Dossenheim sites in Germany as early as the second half of 2021 as part of a strategic partnership with vaccine manufacturer BioNTech.

DuPont to open new production line for electronics materials in Ohio

February 11, 2021 — DuPont Interconnect Solutions, a unit of DuPont Electronics & Industrial (Wilmington, Del.; www.dupont.com/electronic-materials), will invest $220 million in an expansion project at the company's Circleville, Ohio site. A new manufacturing line is expected to be completed in the second half of 2021 to expand production of Kapton polyimide film and Pyralux flexible circuit materials for the automotive, consumer electronics, telecom, industrial and defense market segments.

Sumitomo Chemical to establish new PP compounds production base in Poland

February 10, 2021 — Sumitomo Chemical Co. (Tokyo, Japan) will establish a new production base in Poland to further enhance its polypropylene (PP) compound business. Sumika Polymer Compounds Poland Sp.z.o.o. (SPCP) will start commercial production in the spring of 2022.

SNF to invest $300 million for polyacrylamide expansion

February 10, 2021 — Specialty chemicals group SNF Holding Co. (Riceboro, Ga.; www.snf.us) will invest $300 million in 2021 and 2022 to produce an additional 30,000 m.t./yr of powder-grade polyacrylamide (PAM) and 100,000 m.t./yr of acrylamide at the company's facility in Plaquemine, Louisiana.

OCI-POSCO joint venture starts construction of hydrogen peroxide plant

February 10, 2021 — OCI Co. (Seoul, South Korea; www.oci.co.kr) and Posco Chemical (Pohang-si, South, Korea; www.posco.com) held a groundbreaking event in Gwangyang-si, South Korea for a new plant to be owned by P&O Chemical, the companies' joint venture. Using a byproduct from steelmaking as a raw material, the new plant will produce 50,000 m.t./yr of hydrogen peroxide to supply semiconductor and display manufacturers. Commercial production will begin in 2022.

Sumitomo Chemical to install new photoresist production lines in Osaka

February 9, 2021 — Sumitomo Chemical will expand production capacity for photoresists, which are light-sensitive resin materials used in advanced semiconductor processes, including argon fluoride immersion and extreme ultraviolet lithography, by installing new production lines at its existing site in Osaka, Japan. The new production lines are due to commence operation in the first half of fiscal 2022.

Mergers & Acquisitions

Lanxess signs contract to acquire Emerald Kalama Chemical

February 15, 2021 — Lanxess AG (Cologne, Germany; www.lanxess.com) agreed to acquire Emerald Kalama Chemical, LLC (Vancouver, Wash.), a manufacturer of specialty chemicals mainly for the consumer segment. The enterprise value of Emerald Kalama Chemical amounts to $1.075 billion. The transaction is expected to be completed in the second half of 2021.

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Chemours splits fluoroproducts business segment

February 11, 2021 — The Chemours Co. (Wilmington, Del.; www.chemours.com) divided its former Fluoroproducts business unit into two new reportable segments: Thermal & Specialized Solutions (TSS, formerly Fluorochemicals) and Advanced Performance Materials (APM, formerly Fluoropolymers). TSS will encompass refrigerant solutions, and APM will include a broad range of brands, including Teflon and Viton.

Elkem acquires organo-functional silicones plant in France

February 10, 2021 — Elkem ASA (Oslo, Norway) agreed to acquire a new manufacturing plant near Lyon, France that is designed for producing highly specialized organo-functional silicones (OFS). The OFS plant is located near Elkem's existing sites, including both the upstream plant in Roussillon, as well as the production site and research center in Saint-Fons. Production at the new site is expected to begin by the end of 2021.

Yara establishes Clean Ammonia business unit

February 10, 2021 — Yara International ASA (Oslo, Norway; www.yara.com) announced its establishment of a new business unit focused on the hydrogen and ammonia economy. The Yara Clean Ammonia global business unit aims to capture growth opportunities within the food and shipping sectors, as well as other ammonia applications.

Arkema acquires Brazil-based adhesives manufacturer Poliplas

February 9, 2021 — Arkema S.A. (Colombes, France; www.arkema.com) announced that its Bostik business has acquired Poliplas, a leader in hybrid-technology sealants and adhesives headquartered in Brazil. With sales around €10 million in 2020, and a plant in São José do Rio Preto, Brazil, Poliplas mainly supplies the construction market.

Lonza to divest Specialty Ingredients business for $4.7 billion

February 9, 2021 — Lonza AG (Basel, Switzerland; www.lonza.com) has entered into a definitive agreement under which private-equity firms Bain Capital and Cinven will acquire Lonza's Specialty Ingredients business for an enterprise value of CHF 4.2 billion ($4.7 billion). Lonza's Specialty Ingredients business operates across 17 manufacturing sites globally, mainly producing microbial-control solutions, composite materials and other specialty chemicals.

Velocys and Toyo advance partnership to develop renewable fuels

February 8, 2021 — Velocys plc (Harwell, U.K.; www.velocys.com) and Toyo Engineering Corp. (Chiba, Japan; www.toyo-eng.com) agreed to start work on commercial projects related to producing renewable fuels in Japan. As part of this new collaboration, the parties have engaged in the preliminary engineering evaluation of a joint effort to deliver a commercial-scale biomass-to-jet-fuel plant in Japan.

Mary Page Bailey

Crystallization: Contributing to Circularity

In a variety of industrial applications, crystallization technologies contribute to the circularity of manufacturing processes and supply chains

IN BRIEF

Crystallization is a major unit operation in the chemical process industries (CPI), typically used for separating and purifying materials in a wide variety of applications, from the manufacture of commodities, such as salts and fertilizers, to pharmaceutical ingredients, fine chemicals and food products. In recent years, much of the demand for crystallization equipment has been due to the rise in demand for battery metals, especially lithium. Driven by the demand for electric vehicles and the push for a more circular economy, lithium producers are increasingly seeking to efficiently recover lithium from resources that may have been previously disregarded due to the presence of impurities. Effective crystallization processes are a critical step in recovering battery-grade lithium from low-quality resources, and technology providers are designing their processes to meet these needs. Furthermore, crystallization is also a cornerstone in other sustainability-focused market sectors, including recycling, bio-based materials and wastewater treatment. This article examines the ways that crystallization technologies are enabling the path to a circular economy.

Battery materials: Purity is key

Purity is absolutely critical in the production of battery materials, and crystallization is essential as a final purification step, especially as some applications now increasingly demand extremely pure materials, emphasizes John Warner, the managing director of JordProxa Ltd. (Perth, Australia; www.jordproxa.com). Consider nickel sulfate, for example, which is a crucial raw material in Li-ion batteries. “Currently, you could consider a de-facto standard of ‘four nines’ purity (99.99 wt.%) for nickel sulfate product destined for use in lithium-ion batteries. That would allow a maximum of 100 mg of impurities per kg of nickel sulfate hexahydrate product. We are now seeing serious consideration being paid to achieving ‘five nines’ purity (99.999 wt.%), which allows just 10 mg of impurity per kg of nickel sulfate hexahydrate product,” says Warner. Meeting these very challenging standards, he says, will require well-designed crystallizers that can significantly ease the requirements imposed upon the upstream refining steps. When considering product purity, crystal size is a crucial parameter. “Growing large crystals is key to purity. Consequently, a better understanding of the balance between growth and stability of operation will be vital,” adds Warner, noting that the understanding of crystal growth in industrial crystallizers has been steadily improving in recent years, enabling equipment to better meet the increasing purity demands of battery-chemical applications.


JordProxa

FIGURE 1. Crystallization and evaporation are crucial purification steps in lithium processing

Resource consumption is another major area of concern for battery manufacturers. “As crystallizers can be operated with renewable energy and use little water, they will be increasingly favored for the production of battery chemicals,” says Warner. Specifically, he mentions that crystallization schemes using mechanical vapor recompression (MVR) exhibit particularly impressive environmental performance when compared to multiple-effect crystallizers, since they not only can use renewable energy sources, but also recover

FIGURE 2. Nickel sulfate, an important component in Li-ion batteries, is purified using crystallizers, as shown in this installation at BHP Nickel West

all evaporated water as condensate without the addition of any cooling water. "MVR technology has improved in both efficiency and capability. New fan designs use less energy for the same duty, and they can compress further to achieve higher equivalent saturated temperatures. Consequently, MVR has become preferred in many applications previously dominated by multiple-effect crystallizers," explains Warner.

Last year, JordProxa designed, fabricated and delivered several large-scale orders for major battery-materials processing sites, including an evaporator and two crystallization plants to lithium producer Albemarle Corp. (Charlotte, N.C.; www.albemarle.com) in Western Australia (Figure 1), and nickel sulfate, cobalt sulfate and ammonium sulfate crystallization plants to Terrafame Ltd. (Tuhkakylä, Finland; www.terrafame.com) in Finland. In 2019, the company delivered a nickel sulfate crystallization plant to BHP Nickel West in Western Australia (Figure 2).

"Crystallization plays a major part in the pathway from raw materials to pure products for lithium sources worldwide. Everyone is looking for high-purity, battery-grade materials," reiterates Robert Buchfink, crystallization product manager for the Chemical business of GEA Group AG (Düsseldorf, Germany; www.gea.com). The major sources for lithium are currently spodumene ore and salt brines, and each resource brings with it unique process considerations when it comes to crystallization. Starting with spodumene, there are several thermal steps up front, including acid leaching and reaction with caustic soda, which result in a mixed solution of mainly lithium hydroxide and sodium sulfate. "This is where crystallization enters the picture. You need to extract very pure lithium hydroxide from such a solution," says Buchfink. Typically, an initial crystallization step will remove most of the sodium sulfate, leaving behind a sodium-sulfate-depleted brine that can be passed to an evaporative crystallization unit, which yields lithium hydroxide crystals. "Sometimes, it will require multiple recrystallization steps to meet purity requirements, so we will dissolve the crystals and recrystallize them with a subsequent crystallization, once more recycling the mother liquors to maximize process yield. All of these steps are simulated in our in-house laboratory using batch or small-scale continuous crystallization trials to demonstrate and confirm that the requested purity is achieved," adds Buchfink.

For dealing with lithium recovery from salt brines, the presence of additional impurities complicates the matter. "Here, you are not only fighting against sodium sulfate, but also many other impurities that are contained in the salt-lake brine, such as calcium, magnesium and borate. The crystallization pathway is tailor-made based on the feed-source impurities to get a pure lithium compound, typically either lithium hydroxide or lithium carbonate," explains Buchfink. For lithium hydroxide, since there are usually not any specifications regarding crystal size, the process will be straightforward, and can use a simple forced-circulation crystallizer. When the end product is lithium carbonate, there is typically an additional precipitation step using carbon dioxide or sodium carbonate. Such precipitation processes may be per-

FIGURE 3. Fertilizer manufacturers are increasingly looking to crystallization technologies to help improve efficiency and product purity

formed either in agitated vessels or a draft-tube crystallizer.

Resource recycling and reuse

A small, but emerging, source of lithium and other battery metals is extraction from recycled end-of-life batteries. "With battery recycling, you're dealing with not only lithium, but also cobalt, nickel and other metals. The purification technologies have to deal with complex mixtures and the real challenge is how to separate the components. This could potentially be done with crystallization," says Buchfink. He adds that GEA has several ongoing battery-recycling studies and contracts at hand that are looking at different process routes and balancing the necessary yield and purity requirements. While many of these projects are currently early in their development, GEA believes that the demand for battery recycling will continue to increase.

Another way that crystallization is contributing to process circularity is salt recovery in the secondary aluminum and wastewater-treatment industries. "In aluminum recycling and remelting, one normally applies a cover salt mixture to protect the melt against oxidation, consisting, for instance, of sodium chloride and potassium chloride. Crystallization enables the continuous re-use of this cover salt mixture in the process, so that users don't have to purchase new salt and there is less waste to deal with," explains Buchfink.

Similarly, salts contained in wastewaters can be crystallized out, enabling easier waste handling and potentially producing a salable salt product. "We have several projects where we look at wastewater and check for a certain concentration of valuable components, for instance, sodium chloride, sodium sulfate or ammonium sulfate. Then, we crystallize it out, and it can be sold or more easily stored, reducing waste-handling costs," notes Buchfink. Such crystallization steps also help move wastewater-treatment processes toward zero-liquid-discharge (ZLD) status. Wastewater treatment operators increasingly prefer handling solid, rather than liquid, waste, and are also driven to increase their use of recycled water. Effective crystallization steps help users to reach these objectives.

Fertilizers and efficiency

In the fertilizer manufacturing sector, environmental factors are also shaping the demands on crystallization processes (Figure 3). "More emphasis has been placed on production of fertilizers that reduce residual soil salinization and improve application to reduce runoff," explains Andrew Duffy, process designer with Veolia Water Technologies' HPD Evaporation & Crystallization group (Plainfield, Ill.; www.veoliawatertech.com). For instance, a major trend observed in the industry is increased interest in the use of sulfate of potash (SOP), a premium fertilizer product used for high-value, chloride-sensitive crops. Typically produced via the Mannheim process, which involves reacting sulfuric acid and KCl in a high-temperature furnace, SOP's production costs and energy consumption can be quite high. However, Veolia has developed several crystallization-based alternatives to the Mannheim process that produce a high-purity SOP product from natural ores, brines, byproduct streams or low-quality KCl sources. "The processes we have developed facilitate the conversion of KCl to SOP through solution chemistry and reaction or evaporative crystallization at lower temperatures," explains Duffy.

Furthermore, he says, because crystallization is a natural purification mechanism, these processes can also enable the utilization of less pure raw-material inputs while still resulting in the same or better SOP product purity as from the Mannheim process. This means that low-purity resources, such as natural brines from evaporated lakes or solution mining, or even waste streams of pulp-and-paper mills, could potentially be used as feedstock for SOP production. To design such an effective crystallization solution for a given combination of feedstock and product-purity demands, it is clear that the project's unique chemistry must be well understood, but Duffy also points out that there are many other important considerations. "We have experienced a significant increase in demand for highly technical solutions that often require laboratory or pilot testing for validation. These may also require a more detailed knowledge of materials of construction, including alternatives to full-alloy vessels, and more emphasis on the control systems, operator training and troubleshooting," he adds, also highlighting remote monitoring and modularization as trending areas of interest in crystallization project design.

Biomaterials

As the focus on environmental sustainability grows, plastics manufacturers are increasingly considering bio-based options. One of the fastest-growing bioplastics on the market is polylactic acid (PLA), which is recyclable, compostable and based on sugar feedstock. As PLA production scales up, effective separation and purification steps are increasingly essential, and crystallization is fundamental to the delivery of high-quality bioplastic materials. Sulzer Chemtech Ltd. (Winterthur, Switzerland; www.sulzer.com) has developed proprietary separation technologies for PLA manufacturing, and has recently licensed them for two major projects in China. In November 2020, Sulzer's crystallization, distillation and polymerization technologies were employed in China's first PLA plant, operated by B&F PLA, to produce 30,000 tons/yr of PLA. In January 2021, the company also announced that it would provide a hybrid distillation-crystallization process to deliver high-purity lactide (an essential PLA building block) for a new project in Ningbo. While crystallization alone is an effective tool for biomaterial production, inserting a distillation stage prior to the crystallization step provides a synergistic effect, says Sulzer. Specifically, fractionation columns serve to maximize throughput, while crystallization achieves extremely high purity levels with low energy consumption while also minimizing degradation risk.

FIGURE 4. Challenging industrial separations often require a combination of different types of process units

The nature of bio-based materials makes their separation especially challenging, which is why a hybrid solution is often necessary. The impurity profiles found in fermentation mixtures are often complex. One example Sulzer mentions is the fermentation of sugar leading to two enantiomers, *L*-lactic acid and *D*-lactic acid. These materials possess very different properties, making it essential that purification processes can obtain material mixtures with the correct *L*/*D* ratio. Furthermore, biomaterial mixtures tend to have components with very similar boiling points, so their separation via distillation requires a great deal of energy input. These materials are also often heat-sensitive and can undergo undesirable reactions, such as polymerization or thermal degradation. Therefore, a separation process that operates at lower temperatures, such as crystallization, is preferred. Beyond offering high-purity products without the risk of thermal degradation, crystallization also decreases energy and solvent requirements, improving the overall sustainability profile for the separation process.

In the case of lactide purification, falling-film crystallizers can be an advantageous option, says Sulzer. In such a unit, a lactide-rich feedstream undergoes stages of cooling and heating. When the temperature within the crystallizers is below the freezing point of the melt, biomaterial crystals build up on the outer surface of the heat-exchanger elements. Impurities are rejected from the growing lactide crystals and are concentrated in the remaining melt. Once the biomaterial is fully crystallized, the impurity-containing liquid phase is drained from the unit, while the crystallized layer remains attached to the heat-exchanger plates. Further purification occurs through partial melting, by gently reheating the process to the melting point. More impurities are removed in the resulting melt. Now, the biomaterial product is totally melted and collected for storage. Any residual material can be separated in a recycling unit and returned to the distillation process to increase product yield. Through subsequent repetitions of this procedure, says Sulzer, it is possible to obtain lactide that is more than 99.9% pure. Sulzer is continuing to advance its bioplastics offerings through the PLAnet consortium, an initiative the company developed alongside Futerro (Celles, Belgium; www.futerro.com) and TechnipFMC (Paris, France; www.technipfmc.com) aimed at supporting the entire PLA value chain with fermentation, purification and polymerization equipment.

Continuous evolution

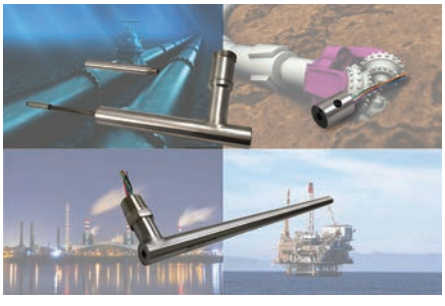
Another transition taking place in crystallization technology is the migration of certain processes from batch to continuous operation. According to GEA's Buchfink, among the products whose production could benefit from continuous crystallization compared to batch are sugars, organic acids and pharmaceutical precursors, as well as some fine chemicals. He emphasizes that capacity expansions can be more effectively realized with continuous crystallizers. "Organic acids, for example, must use large agitated vessels in batch mode. A major advantage of continuous crystallization is that you don't need to add twenty more tanks to increase capacity, maybe just one or two continuous crystallizers will work," he adds, noting that medium-scale projects in the range of 1 to 10 ton/h are the best candidates for the transition from batch to continuous. Alongside continuous processing, advanced process analytical technologies (PAT), such as focused-beam reflectance measurement, visual particle measurement and acoustic signaling for spectroscopic examination, are helping improve crystallization processes, says Wayne Genck, president of Genck International (www.genckintl.com). "While many PAT methods have been used in the laboratory, there is an increased application in pilot and commercial units. The goal is to reduce cost while achieving product quality, including purity, crystal size distribution, polymorph form, morphology, bulk densities, solubility and dissolution rates," he explains. ■

Mary Page Bailey

Focus on Sensors

SICK

AVT Reliability



NewTek Sensor Solutions

Oxygen measurement with Ex approvals & SIL2 certification

The new Zirkor200 oxygen-measurement analyzer (photo) adds features for integration into safety-related process controls. The user-friendly, extremely rugged and precise zirconium-dioxide analyzers are not only available for gas explosion-hazardous areas (Zirkor200 Ex-G), but for use in dust explosive atmospheres (Zirkor200 Ex-D) as well. The Zirkor200 now also features SIL2 certification for integration into safety-related process controls. Both explosion-proof variants are approved in accordance with ATEX and IECEx. The Zirkor200 Ex-G for Zone 1 works well primarily in the chemicals, petrochemicals, refineries and oil-and-gas industries. With the Zirkor200 Ex-D for Zone 21, the focus is on applications in the cement and power-generation industries, and in the fields of waste-processing and recycling. In the majority of these industries, the Zirkor200 with SIL2 option also enables safety-relevant measurements with only one system (1oo1; one out of one). The analyzers of the Zirkor200 series handle process-gas temperatures up to 1,600°C. — *SICK Inc., Minneapolis, Minn.*
www.sick.com

Ensure sensor configuration-data integrity with this module

Sensor Data Integrity is a new Automation Integrity module that enables industrial organizations to ensure configuration-data integrity for smart and traditional sensors with signal tracing and validation. This addition to Automation Integrity helps reduce both process safety and cybersecurity risk in support of digital transformation and Industry 4.0 initiatives. The new Sensor Data Integrity module provides multi-vendor: discovery of smart, industrial internet of things (IIoT) and traditional analog sensors; visibility to the complete inventory and potential cyber vulnerability for sensors; creation of templates to define approved configurations for each sensor type; automated detection of configuration errors; automated identification of devices that do not match assigned templates; cross-checking of parameters; support for large-scale, multi-site sensor deployments; and sensor signal tracing, validation and visualization. The information provided by Sensor Data Integrity can also be leveraged by sensor asset-management systems (AMS) to support instrument calibration, and can feed PAS Cyber Integrity to support cybersecurity vulnerability assessments. — *PAS Global LLC, Houston*
www.pas.com

Vibration & temperature sensor receives UL 61010 certification

This company has strengthened its position in the U.S. and Canadian asset-management market after achieving the UL 61010 US and C safety standard for its tri-axial fixed vibration and temperature sensor, Machine Sentry MSF-1 (photo). UL 61010 is the U.S. and Canada equivalent of the European CE product-safety standard and covers electrical products for use in non-hazardous locations. The MSF-1 sensor is a wireless intelligent tri-axial vibration and integrated temperature sensor, which connects via Bluetooth. Storing up to 5,000 readings and with a five-year battery life, it can be installed anywhere from harsh environments, such as chemical plants and the oil-and-gas industry, to the food-and-beverage sector. — *AVT Reliability Ltd., Warrington, Cheshire, U.K.*
www.avtreliability.com

LVDTs in different alloys for challenging environments

This company offers its linear variable differential transformer (LVDT) Position Sensors (photo) in a range of construction materials to provide highly accurate and reliable position measurement for applications with extreme conditions. In addition to stainless-steel, special alloys, such as Monel, Inconel, Hastelloy and Titanium, are used to extend the reliability of its displacement sensors in challenging environments with radiation, seawater and corrosive acids, as well as high or low temperatures and pressures. Materials for LVDT construction are chosen for each in-

dividual application. — *NewTek Sensor Solutions, Pennsauken, N.J.*
www.newteksensors.com

These CO_2 sensors require very little power

The CozIR-LP3 ultra-low-power CO_2 sensor (photo) includes on-board power management, allowing the user to control sensor power consumption during measurements and when the sensor is inactive. The user can reduce active current consumption to less than 1 µA without switching off the sensor. The CozIR-LP3 is based on the company's proprietary solid-state non-dispersive infra-red (NDIR) LED technology, where the sensor measures concentration levels by analyzing the amount of light absorbed by the CO_2 gas. Users have a choice of UART or I2C control interfaces, digital and analog CO_2 measurements and a fail-safe digital alarm level monitor. — *Gas Sensing Solutions, Cumbernauld, U.K.*
www.gassensing.co.uk

An integrated 900-MHz sensor network-to-cloud solution

This company's wireless sensor network has been integrated with Machfu's Industrial IoT Gateway (photo). The gateway incorporates edge intelligence, multi-protocol translation capabilities and multi-dimensional security features, resulting in a versatile and secure sensor-to-cloud solution. Operating this company's Edge Application on Machfu's Edge Gateway enables users to easily and wirelessly bring all sensor measurements from a sensor network into their cloud application. With a single click, the IIoT Gateway automatically communicates with the gateway to discover wireless nodes in a network, collect measurements from sensors and transmit them over cellular, WiFi or Ethernet connections. — *SignalFire Wireless Telemetry, Marlborough, Mass.*
www.signal-fire.com

Measure CO_2 concentrations with this sensor chip

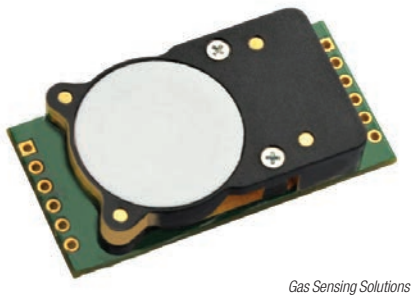
The STC31 sensor (photo) is a chip-sized gas-concentration sensor for high-range, accurate CO_2 measurements designed for high-volume applications. The sensor is based on a thermal-conductivity measurement principle, which results in superior repeatability and long-term stability. This makes the STC31 suitable for applications such as cold-chain logistics where reliability is key. The sensor features a digital I2C interface, which makes it easy to connect directly to a microprocessor. The accuracy is 0.5 vol.%. and ±3% of measured value and the response time is faster than 1 s. — *Sensirion AG, Stäfa, Switzerland*
www.sensirion.com

A multi-parameter, handheld device and pH electrode

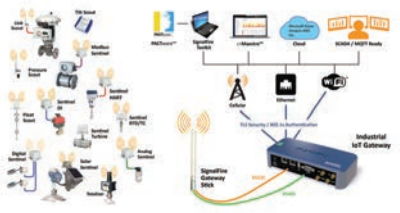
The Liquiline Mobile CML18 handheld device and Memosens CPL51E laboratory pH sensor (photo) were introduced last November. The multiparameter handheld device enables easy and reliable monitoring of a variety of critical measured values. The CML18 and the CPL51E pH electrode can be paired together for applications in the laboratory or for grab-sample analysis in the field. Historically, different products are used for laboratory analysis versus process measurements. With the Liquiline Mobile CML18 device, the same Memosens sensors that are used in the process can also be used in the laboratory. This guarantees complete consistency of data. The Liquiline Mobile CML18 device can be operated easily using the intuitive SmartBlue application (app). All measured values and sensor data are transferred via a secure Bluetooth connection to the app on a smartphone or tablet. — *Endress+Hauser, Greenwood, Ind.*
www.us.endress.com

Inventory-management software for HART sensors

Binventory (photo) is an advanced inventory-management software that enables plants to manage level data from all vessels with a single program. This allows users to monitor the level of solids or liquids in bins, tanks, or silos from one platform. Binventory is now compatible with sensors using the HART protocol or Modbus output. Binventory works with many types of sensors, including non-contact-radar and guided-wave radar used for level measurement. The software allows for bulk densities and strapping tables to be entered for solids, while entering specific gravity for liquid tanks ensures accurate volumes. Complex vessels of different shapes and sizes



Gas Sensing Solutions



SignalFire Wireless Telemetry

Sensirion

Endress+Hauser

BinMaster

Sigma-Netics

Rechner Electronics Industries

Hans Turck

Baumer

Nexen Group

are easily configured, such as horizontal tanks, split silos, and non-linear tanks. Users can program automated alerts, access real-time inventory levels and generate historical reports from up to 255 vessels on their PC or tablet. — *BinMaster, Lincoln, Neb.*
www.binmaster.com

Pressure transducers for harsh environments

This company offers durable pressure transducers (photo) that can withstand radiation, fatigue, submersion in underwater vehicles and high pressures in excess of 30,000 psi. Available models include: a general industrial pressure transducer with wetted material alternatives, extended thermals and pressure ranges to 25,000 psi; a radiation-tolerant mV/V pressure transducer; a high-pressure, fatigue-rated transducer for pressures in excess of 100,000 psi; a multi-purpose aerospace pressure transducer, which features shunt calibration, multi-temperature thermal sensor characterization and cryogenic options; and more. — *Sigma-Netics, Inc., Riverdale, N.J.*
www.sigmanetics.com

This capacitance sensor can take the heat

The new KA7000 capacitance sensor (photo) has a temperature rating of 120°C (248°F). Its polyamide housing has a high resistance to abrasion, so operation with granular material is not an issue. The sensor is also not disturbed by high vibrations. The sensor is fully potted, making it water- and dust-tight with IP67 protection. The sensor operates at 12–30 V, has a sensing range of 2 to 25 mm and is suitable for dryer applications. — *Rechner Electronics Industries, Inc., Sanborn, N.Y.*
www.rechner.com

Compact temperature sensors with plug-and-play options

This company is expanding its range of fluid sensors with IO-Link-capable sensors for flexible and reliable process temperature measurement. Both compact devices are equipped with an integrated temperature probe (TS700), as well as processing and display units (TS720) for connecting resistance thermometers or thermocouples (photo). The TS+ sensors meet the growing demand for straightforward commissioning and high plant availability. This is supported by the robust stainless-steel housing with touch operation instead of mechanical operating elements, which are ideally suited for use in harsh industrial environments thanks to IP67 and IP69K protection. Besides process values, the IO-Link interface provides the user with a large volume of condition-monitoring data for smart IIoT applications. To simplify commissioning, the TS+ devices also feature automatic detection of the output type (PNP/NPN or current/voltage), as is already offered by the PS+ and FS+ pressure and flow sensors. Compact TS700 devices operate in a measuring range from –50 to 150°C. Type TS720 processing and display units can be designed to cover temperature ranges between –200 and 1,800°C. — *Hans Turck GmbH & Co. KG, Mülheim an der Ruhr, Germany*
www.turck.com

Monitor and control three variables with a single sensor

With the PF55S and PF75H/S electromagnetic flowmeters (photo), it is possible to measure volumetric flow, flow velocity and temperature — three of the most important variables that help to ensure efficient process control. Designed for industrial applications, these compact flowmeters are suitable for applications with high flow velocities up to 10 m/s, with the PF75H/S capable of measuring media with a conductivity of 5 µS/cm and available in a hygienic or a robust industrial design. Thanks to the design of these electromagnetic flow sensors, precision combined with long-term stable and reliable measurement is assured with accuracy of up to 0.2%. The combination of precise measurement of volumetric flow and flow velocity means tasks such as volume balancing, mixing and dosage processes can be optimized and controlled very accurately. — *Baumer Ltd., Swindon, U.K.*
www.baumer.com/gb/en

New sensors to enhance IIoT connectivity for brake lines

This company's Servo, Rail, and ZSE brake lines (photo) now have Industry 4.0 connectivity sensor options to enhance machine efficiency. Multiple sensors integrated into the brake families provide information about brake operation and health to the control system network. For example, the sensors used in the spring-operated, air-released ZSE brakes provide operation information such as brake en-

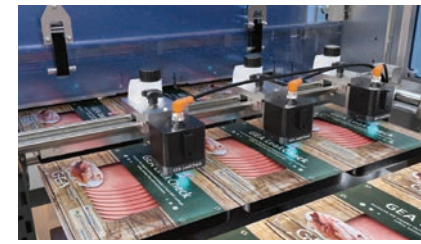
gagement/disengagement and temperature. Information provided by the sensors is shared with the control network to aid in motor/drive programming, avoid brake overheating, and extend brake life. ZSE flange mounted, through bore, spring engaged brakes provide true zero backlash, low inertia, and high rigidity for precision holding applications. Rated for more than 2,000,000 holding cycles. — *Nexen Group, Inc., Vadnais Heights, Minn.*
www.nexengroup.com

Collaboration to reduce waste from grain storage and transport

This company is now collaborating with TeleSense, Inc. (Sunnyvale, Calif.; www.telesense.com) to introduce monitoring solutions for post-harvest commodity storage and transport to multiple stakeholders across the agriculture value chain. This partnership is said to represent a new vision for how grain is stored, handled and transported by creating a more efficient, data-driven supply chain that will reduce food waste, improve food quality and increase sustainability. TeleSense uses scalable sensor technology on an artificial intelligence (AI) platform to monitor the temperature, humidity and CO_2 levels of stored grain. It leverages fixed and portable sensors to monitor the current and future condition of stored grain, while automating the detection and mitigation of potential issues such as hotspots, excess moisture or pests. Machine-learning algorithms provide users with alerts needed to effectively manage and predict grain quality, ensure safety, improve operational efficiency and increase profitability. Adding TeleSense technology to this company's portfolio complements its range of gas monitoring, safety and detection devices, as well as fumigants. — *UPL Ltd., Mumbai, India*
www.upl-ltd.com

Sensors measure the oxygen content of MAP packs

LeakCheck (photo) is a new in-line measurement system capable of checking seal and package integrity on all forms of modified atmosphere packs (MAPs). LeakCheck uses an



GEA

in-line process on the company's thermoformer to test the seal and package integrity on each individual MAP. The residual O_2 content in each package is first measured with a fluorescent sensor spot printed on the inside of the top film. Optical sensors mounted on the thermoformer project light onto the sensor spot, gauging the wavelength of the light emitted by the dye to accurately determine the O_2 content. Next, packages are subjected to over- and underpressure in a stress unit before a second contactless measurement is taken. If the new result differs from the first, the package seal is broken. — *GEA AG, Düsseldorf, Germany*
www.gea.com

Gerald Ondrey

New Products

Dinnissen

Collect up to 20 different-sized samples with this carousel

With the Multisize Sample Carousel (photo), producers can now take samples of different sizes in an automated sampling process. Producers can also determine the order and frequency per sample size. This allows for the automated serial collection of samples for different purposes, such as starter samples, chemical samples, bacteriological samples, hourly samples and batch samples. The Multisize Sample Carousel collects up to 20 samples in different container shapes, without human intervention. The system can be seamlessly integrated into new and existing production lines and reduces downtime to a minimum. — *Dinnissen B.V., Sevenum, the Netherlands*
www.dinnissen.eu

IDEC

Free firmware upgrade adds MQTT IIoT support

This company has released a free firmware upgrade enabling new and existing MicroSmart FC6A Plus PLC CPUs (photo) to support the industry-standard MQTT protocol. The upgrade can be downloaded to the FC6A CPU, so it is easy for users to connect all types of field data to on-site and cloud-based brokers, and make the information readily available for users and analytical applications. Users can also send commands to the FC6A using MQTT. MQTT has emerged as the preferred industrial internet of things (IIoT) communications protocol because it uses a lightweight and efficient publish/subscribe methodology for secure messaging between devices and centralized brokers, making information easily available for all authorized applications. A large number of clients can publish data to the broker, subscribe to any broker data, or bi-directionally do both. — *IDEC Corp., Sunnyvale, Calif.*
www.idec.com/usa

Valley Forge & Bolt Mfg.

Monitor tension remotely with this Web-based sensor

The UHF Band RTM (remote tension monitoring) meter (photo) is a wireless bolt-monitoring system that can be used to remotely monitor the tension in critical joints. This wireless sensor detects and collects the tension level in a bolted joint as read by the company's SPC4 fastener, and then relays the data to a facility's condition monitoring/SCADA system. Users can also program the sensor to take measurements at prescribed intervals and send alerts if a bolted joint falls outside of chosen tension parameters. The meter operates in 433/868/915 MHz frequencies, which makes it suitable for applications in the industrial, scientific and medical sectors. — *Valley Forge & Bolt Mfg. Co., Phoenix, Ariz.*
www.vfbolts.com

ACS Motion Control

A new intelligent drive module for machine builders

This company has launched the first in a new line of high-performance intelligent drive module (IDM) products. The IDMsm (photo) is a two- or four-axis EtherCAT DS402 universal servo drive featuring unique control algorithms and processing technologies that enhance the performance of high-precision motion stages. Certified as EtherCAT Conformance Tested, the IDMsm provides up to 5 A continuous and 10 A peak per axis, with 12–48 V d.c. drive supply. — *ACS Motion Control, Ltd., Yokneam Illit, Israel*
www.acsmotioncontrol.com

Siemens

A new actuator line for small valves and multitasking

This company has upgraded its range of SSA actuators for small valves by adding new features for more energy-efficient and versatile hydronic-room applications. The updated SSA actuators now offer more flexibility due to their broad control possibilities — from analog control to KNX communication capabilities for room solutions and fast integration into connected systems. While using the same cable for communication and power, the user saves time and cost, says the company. Thanks to the "nightmode" operating configuration, the actuators are more silent than ever, with less than 28 dB acoustical emissions. This makes them ideal for use in noise-sensitive areas. New functionalities, such as feedback signal and the possibility of switching to manual mode, save time and costs. — *Siemens AG, Berlin and Munich, Germany*
www.siemens.com

Exciter technologies improve vibrating-screen performance

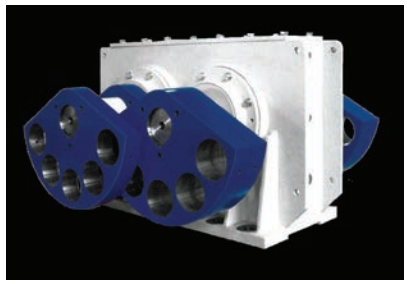
Niagara brand vibrating-screen exciters (photo) are offered in four models, each of which is adjustable to provide eight weight configurations, delivering a large static-moment range. These exciters come standard on all of this company's exciter-driven XL-Class and L-Class vibrating screens, and are also available as aftermarket parts for any brand of exciter-driven machine. Exciter-driven vibrating screens are ideal for high-tonnage applications and heavy-duty environments, such as dewatering or semi-autogenous grinding (SAG) mill screening, due to the equipment's strength and advanced sealing system. These exciters are engineered to set the required stroke, frequency and exact static moment for each application, resulting in improved screening performance. The average lifespan of a Niagara Exciter is 15,000 h. *— Haver & Boecker Niagara, St. Catherines, Ont., Canada*

www.haverniagara.com

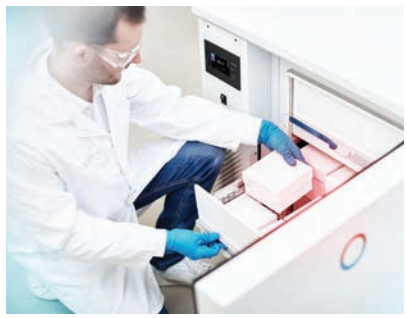
Ultra-freezers for safe storage of vaccines and valuable samples

Versafreeze ultra-freezers (photo) have been optimized for the extreme requirements of deep-freeze storage for vaccine producers, pharmaceutical service providers and research laboratories, ensuring the safe storage of temperature-sensitive vaccines, valuable medicines, chemical substances or biological samples. With a temperature range from 0 to –85°C, Versafreeze ultra-freezers provide state-of-the-art refrigeration technology, excellent insulating properties and reliable protection, thanks to password-protected access rights and secure monitoring. The Versafreeze freezer cabinets and chest freezers use a combination of vacuum insulation panels, thermofoil and diffusion-resistant foamed polyurethane insulation to protect against warming. *— Lauda Dr. R. Wobser GmbH & Co. KG, Lauda-Königshofen, Germany*

www.lauda.de



Haver & Boecker Niagara



Lauda

B&W Tek

Hoyer

TLV

Brüel & Kjær Vibro

Handheld Raman instruments meet USP requirements

NanoRam and NanoRam-1064 handheld Raman instruments (photo) are calibrated in compliance with the wavelength accuracy criteria for qualitative Raman measurements set forth by all global pharmacopeias, including the new USP 858 and 1858 chapters. The system software of NanoRam and NanoRam-1064 devices includes performance validation testing using Raman-shift standard materials as defined by the ASTM E1840 Standard Guide for Raman Shift Standards for Spectrometer Calibration. The NanoRam systems include a variety of sampling accessories optimized for the measurement of materials in the form of liquids, gels, powders or solids under either laboratory settings or demanding industrial conditions. — *B&W Tek, LLC, Newark, Del.*

www.bwtek.com

The latest generation of titanium tanks

Under contract to a major chemical industry manufacturer, this company's engineers developed a new generation of titanium tank containers (photo) for highly corrosive dangerous goods. After two years of intensive development work and construction time, two units were brought into operation in January 2021. The project team made a successful breakthrough by attaching the steel frame to the titanium tank, and also designed a high-performing heating system. The two new titanium tank containers were developed and built specifically to transport molten monochloroacetic acid (MCA). This company leases the containers to a chemical industry user with worldwide operations, for which it transports the highly corrosive product at an elevated temperature. Because conventional rubberized or coated stainless-steel tank containers do not withstand the product requirements and transport conditions, this customized solution made of titanium was developed. — *Hoyer GmbH Internationale Fachspedition, Hamburg, Germany*

www.hoyer-group.com

A condensate-recovery system for high-temperature operations

The GP14 Power Trap (photo) is an advanced condensate-recovery system for pumping high-temperature condensate for vented receivers, sumps and other important pump applications. The GP14 provides high-pressure, high-temperature condensate pumping services up to 392°F and 200 psig. The device's non-electric design ensures no cavitation or seal leakage. A contoured body design can increase energy savings, and the durable Inconel compression spring comes with a lifetime spring warranty. Serviceability is improved due to an externally removable motive valve, which is also protected by an internal secondary screen. The GP14 PowerTrap is available in cast iron or cast steel, with connection sizes of 3×2 NPT, 2×2 and 3×2 flanged. — *TLV Corp., Charlotte, N.C.*

www.tlv.com

This palm-sized device monitors machine health

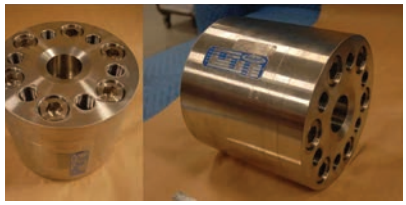
The new Vibrostore 100 (photo) is a palm-sized device that provides vibration-level and bearing-wear monitoring for balance-of-plant machines at the push of a button. The lightweight device can be used single-handedly, and enables even untrained personnel to take vibration measurements and assess a semi-critical machine's overall vibration condition. The instrument is equipped with a pre-set cable-connected Vibro acceleration sensor. Once the type and size of the machine (based on the ISO 10816 standard related to mechanical vibration) and its running speed are entered, a one-button push can perform the measurement. A traffic-light display immediately indicates the severity of the vibration based on the built-in ISO 10816 alarm limits (velocity in mm/s or in./s). The main screen also shows the rolling-element bearing condition in bearing damage units measurement (BDU) and total *g* (RMS acceleration). The display of the vibration level in frequency ranges indicates the most common machine faults, such as imbalance, misalignment or looseness. — *Brüel & Kjær Vibro GmbH, Darmstadt, Germany*

www.bkvibro.com

New check valves designed for urea service

This company recently introduced a new in-line, axial check valve for urea and ammonia service (photo). Standard sizes range from ½ to 6 in. with flanged, butt weld, hub, lens ring or custom connections. This company's urea service valves may be supplied in many alloys, including urea-grade 316L, Ferralium 255, 310 MoLN, Duplex F51, Super Duplex F53, 25-22-2 SS, Zeron 100 and Titanium. Valve features include: integral gland wrench for concentric 360-deg packing load; inline renewability; two-year warranty; standard helium leak testing; and optional steam jacketing. — *Conval Inc., Enfield, Conn.*

www.conval.com



Conval

Use these fans in high-pressure, high-flow applications

New BC-2200 backward-inclined fans (photo) are designed for high-flow, high-pressure applications handling clean air and light particle-laden or moist-air gas streams in a variety of applications, including thermal oxidation, steelmaking, combustion air, ethanol production, petroleum refineries, dust or fume control, quench cooling and glass production. A BC-2200 fan can be designed to handle temperatures from –50 to over 800°F and can be constructed using a variety of special alloys, such as Hastelloy, Inconel or Carpenter 20, to meet application demands. The fan reaches a volumetric flowrate of 60,000 ft^3/min and can be customized according to customer specifications, with options including specialized alloys or coatings, heat-fan construction and spark-resistant construction. To make maintenance easier, two types of split housing options allow for easy access to internal components without disturbing the inlet/outlet connections. Additional accessories, such as cleanout doors and drains, further ease maintenance burdens. — *The New York Blower Company, Willowbrook, Ill.*

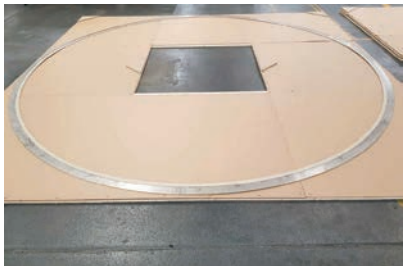
www.nyb.com

The New York Blower Company

SPX Flow

Vaisala

Lee Products



The Flexitallic Group

Dwyer Instruments

New tank outlet valves for sanitary applications

This company has added a new model of tank outlet valve to its APV D4 series of mix-proof valves (photo). The new D4 valves enable users to clean the pipeline without having to empty the contents of the tank, which improves efficiency and eliminates changeover requirements. APV D4 valves effectively provide reliable separation between the tank and servicing pipelines in sanitary applications across many industries, including food and beverage, dairy, pharmaceuticals and cosmetics. Standard features include a seat lift actuator, cross-port housing and a leak drain with clamp connectivity for clean-in-place (CIP) fluid collection. — *SPX Flow, Inc., Charlotte, N.C.*
www.spxflow.com

Humidity and temperature transmitters for hazardous areas

The new Humicap HMT370EX series of intrinsically safe humidity and temperature transmitters (photo) are designed specifically for hazardous and explosive environments. The entire transmitter can be installed directly in explosive areas, up to Zone 0 and Zone 20, with no need for additional protective enclosures. Thanks to its rugged display, the transmitter can withstand continuous exposure to potentially explosive areas that contain flammable gases or dust. Typical applications for HMT370EX include hydrogen-cooled generators in electricity generation, chemical manufacturing and processing, pharmaceuticals manufacturing, oil-and-gas drilling platforms and fuel tanks and storage. The HMT370EX series offers a wide selection of probe options for wall mounting, confined spaces, pressurized spaces and more. — *Vaisala Oyj, Vantaa, Finland*
www.vaisala.com

This solenoid valve enables efficient switching

The Xover solenoid valve (photo) is designed to switch quickly and efficiently between samples, reagents, cleaning solutions or calibrants. The Xover valve features a Y-shaped elastomer tube in a three-way configuration, which results in a design that combines the flow path of a pinch valve with the versatility and maintenance-free performance of a chemically inert isolation valve. This means that it is easily flushed and ensures fast, efficient fluidic performance with lower power consumption, according to the manufacturer. The Xover's features make it suitable for a wide range of applications, including scientific instrumentation, drug discovery, analytical chemistry and any fluidic application where low internal and zero-dead volume and inert materials are critical. — *Lee Products Ltd., Buckinghamshire, U.K.*
www.leeproducts.co.uk

New large-diameter fire-safe gasket delivered

This company has delivered its largest ever Flexpro gasket (photo) to be used in the development of a propane dehydrogenation (PDH) plant in the U.S. The gasket, with a diameter in excess of 5 m, is faced with Thermiculite, a material possessing heat and chemical resistance and is rated to withstand temperatures up to 1,000°C. The versatile, fire-safe gasket material also eradicates graphite oxidation, which limits seal life, and is highly effective in maintaining joint integrity in demanding environments. Flexpro gaskets are available in several styles and can be manufactured to recognize international standards or to suit customized connections. — *The Flexitallic Group, Houston*
www.flexitallic.com

Differential-pressure gages are protected in hazardous areas

The AT-2000 Magnehelic differential-pressure gage (photo) is ATEX/IECEx approved and incorporates a flameproof aluminum enclosure with textured epoxy coating that protects the device for use in hazardous areas commonly found in chemical processing or other industrial applications. The AT-2000 gage is designed for monitoring pressure, vacuum and differential pressure. Due to the mechanical design of the gage, there is no need for local power to monitor pressure changes. The AT-2000 includes a standard windowed enclosure cover that allows users the ability to visually verify changes in the process. — *Dwyer Instruments, Inc., Michigan City, Ind.*
www.dwyer-inst.com
Mary Page Bailey and Gerald Ondrey

Thermal Oxidizer Selection

Department Editor: Scott Jenkins

Thermal oxidizers are pollution-control units designed to prevent process-generated volatile organic compounds (VOCs) from entering the environment. Different technologies offer tradeoffs among initial cost, operating expense, complexity, emissions, fuel efficiency and destruction efficiency. This one-page reference provides information on selecting thermal oxidizers.

Thermal oxidizer designs vary widely, but can be generally split into three main categories: direct-fired, regenerative and catalytic. A thermal oxidizer sustains the proper conditions for oxidization of the combustible materials in three ways: by maintaining an operating temperature sufficiently above the autoignition point of the gas, by providing enough time for combustion and by introducing excess oxygen to complete the oxidation reactions.

Direct-fired thermal oxidizers

Direct-fired thermal oxidizers use a burner to heat a chamber to proper oxidation temperatures for the required destruction efficiency. The chamber must be designed to maintain an adequate residence time and provide sufficient velocity for turbulent mixing. If the process gas has sufficient heat content, it can be used as the fuel gas for the burner. Otherwise, supplemental fuel is required. A recuperative thermal oxidizer is a variation that incorporates heat recovery. Direct-fired thermal oxidizers offer high destruction efficiencies (up to 99.99%) and can provide low NOx and CO emissions.

Regenerative oxidizers

Regenerative thermal oxidizers are used for applications where the combustible concentration is below 3% of the lower explosivity limit. This type employs ceramic media to capture heat from oxidation to reach thermal efficiencies of up to 98%. Thermal energy is retained by the ceramic media and is then used to heat and oxidize the process gas as it enters.

To accomplish this, the system uses multiple beds and alternates the inlet and outlet of the oxidation chamber. A two-bed system would cycle about every two minutes, allowing heat to be captured by the ceramic media on the outlet and heating the process gas from residual heat in the inlet bed. Once the system cycles, the direction of flow is reversed, allowing the temperature to be regenerated on the beds. Regenerative thermal oxidizers can operate on little to no fuel and achieve 98.5% destruction efficiency with low NOx and CO emissions, even with lean process gases. Adding a purge step to the cycle requires an additional bed, but increases destruction efficiency to 99.5%.

Catalytic thermal oxidizers

A catalytic thermal oxidizer utilizes a catalytic bed to promote oxidation, lowering the temperature required to oxidize the process gas. Due to the lower temperature, a catalytic thermal oxidizer uses less fuel than a direct-fired model and can even be designed to be self-sustaining through the use of a heat exchanger to pre-heat the process gas. This type of system is limited by the combustible concentration of the process gas and is limited to components that will not poison the catalyst. For the correct applications, a catalytic thermal oxidizer can offer high destruction efficiency and low NOx and CO emissions.

Selection guidance

When selecting a combustion system, emissions and destruction efficiency have become the primary criteria. In general, the decision factors should prioritize process-gas composition, followed by emissions, and then fuel efficiency and capital costs.

Handling challenging components. Corrosive components, such as H_2S and halogenated chemicals, demand systems capable of safely disposing of them. Once concentrations of any of these compounds reaches a certain level, typically the safest and most effective way to destroy them is through specially designed direct-fired thermal oxidizers. Catalytic thermal oxidizers and regenerative thermal oxidizers are not suitable, because they are too sensitive to the presence of these chemicals.

FIGURE 1. Regenerative thermal oxidizers capture the heat from oxidation, and retain it with ceramic media

Destruction efficiency. A simple enclosed combustor (flare) will achieve about 98% destruction efficiency. Up to 99.5% destruction efficiency can be achieved with a temperature-controlled combustor, a regenerative thermal oxidizer or a catalytic thermal oxidizer. Above that, a direct-fired thermal oxidizer or an ultra-low-emissions combustor is required.

NOx emissions. Although they offer great destruction efficiency, direct-fired thermal oxidizers do not improve much over simpler combustors in NOx generation. Several low-NOx burner designs can improve NOx emissions for direct-fired thermal oxidizers. Ammonia-injection systems can lower NOx, but can be expensive. Regenerative and catalytic thermal oxidizers offer lower NOx emissions.

Fuel efficiency. Regenerative thermal oxidizers offer the best fuel efficiencies, recovering up to 98% of thermal energy. These systems are ideal for low-concentration and high-flowrate applications. Catalytic thermal oxidizers can also operate at high thermal efficiencies by incorporating heat exchangers to pre-heat the process gas before it passes through the catalyst. Recuperative thermal oxidizers can be used to pre-heat process gas to raise fuel efficiency, or to recover heat for use in another part of the plant. ■

Editor's note: This "Facts at your Fingertips" is based on material from Vij, A.D., Enclosed Combustion Equipment and Technology, *Chem. Eng.*, January 2018, pp. 46–49.

Acrylonitrile Butadiene Latex Production

By Intratec Solutions

Nitrile rubber (also known as NBR, acrylonitrile butadiene rubber, acrylonitrile butadiene latex, Buna-N) is a synthetic polymer made of monomers 1,3-butadiene and acrylonitrile. This rubber is known for its resistance to chemicals, oils and fuels. NBR is produced with a wide range of molecular weights and monomer ratios, so basic polymer properties can vary greatly.

NBR is primarily used in applications where good oil resistance is required, such as rubber seals and O-rings, hose and belting stock and blowout preventers or packers (in oil drilling). NBR is also used in molding miscellaneous parts, rubber latex products, sponge applications, gaskets, pump stators, safety gloves and footwear. Additionally, NBR is used in modifying plastics, adhesives, cements, sealants, coatings and friction materials.

The process

The present analysis discusses an industrial process for acrylonitrile butadiene latex production. The process comprises two major sections: (1) polymerization; and (2) monomers recovery (Figure 1).

Polymerization. Polymerization occurs in continuously stirred, jacketed tank reactors connected in series. To maintain a low reaction temperature, all reactors are cooled by means of ammonia vaporization. Acrylonitrile and butadiene are mixed with an emulsifier, demineralized water and other chemicals to form the emulsion that will be fed to the polymerization reactors. Downstream, a "shortstop" agent is mixed with the emulsion in order to stop reaction at the desired conversion. This avoids gel formation.

Monomers recovery. The latex generated in polymerization reactors is flashed at atmospheric pressure and then under vacuum. Residual butadiene vapors are compressed and then cooled for condensation. The condensed stream is directed to a decanter for water removal. Recovered butadiene is recycled to a butadiene plant, where butenes are separated, so the recovered butadiene can be reused in the NBR latex plant. The degassed latex is pumped and fed to a vacuum plate column, where residual acrylonitrile monomer is stripped by contacting the latex with steam entering the column bottom. Stripped acrylonitrile is recycled to the polymerization stage. The latex is mixed with an antioxidant agent and finally blended into a homogeneous emulsion before being sent to storage facilities as the finished latex product.

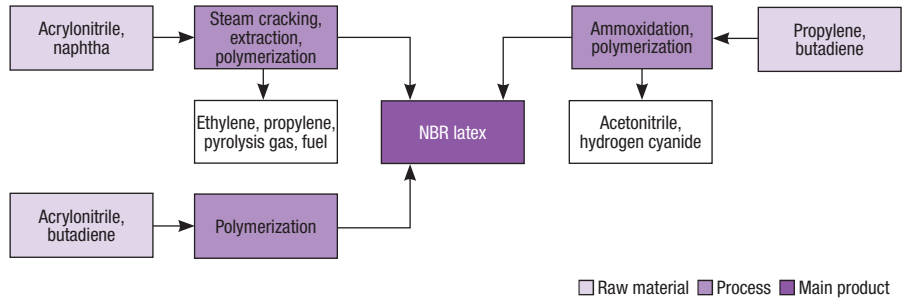


FIGURE 2. The most common NBR latex production pathways are shown here

Production pathways

Nitrile rubber latex production basically consists of the emulsion polymerization of 1,3-butadiene and acrylonitrile, so different NBR manufacturing routes are related to different sources of the monomers used. The most typical NBR latex production routes are based on acrylonitrile produced via ammoxidation of propylene and butadiene produced via isolation from C4 steam-cracker fractions (Figure 2).

Economic performance

The total operating cost (raw materials, utilities, fixed costs and depreciation costs) estimated to produce NBR latex was about $2,000 per ton of NBR latex in the first quarter of 2017. The analysis was based on a plant constructed in the U.S. with capacity to produce 35,000 metric tons per year of acrylonitrile butadiene latex.

This column is based on "Acrylonitrile Butadiene Latex Production – Cost Analysis," a report published by Intratec. It can be found at: www.intratec.us/analysis/nitrile-rubber-production-cost. ■

Edited by Scott Jenkins

Editor's note: The content for this column is supplied by Intratec Solutions LLC (Houston; www.intratec.us) and edited by *Chemical Engineering*. The analyses and models presented are prepared on the basis of publicly available and non-confidential information. The content represents the opinions of Intratec only. More information about the methodology for preparing analysis can be found, along with terms of use, at www.intratec.us/che.

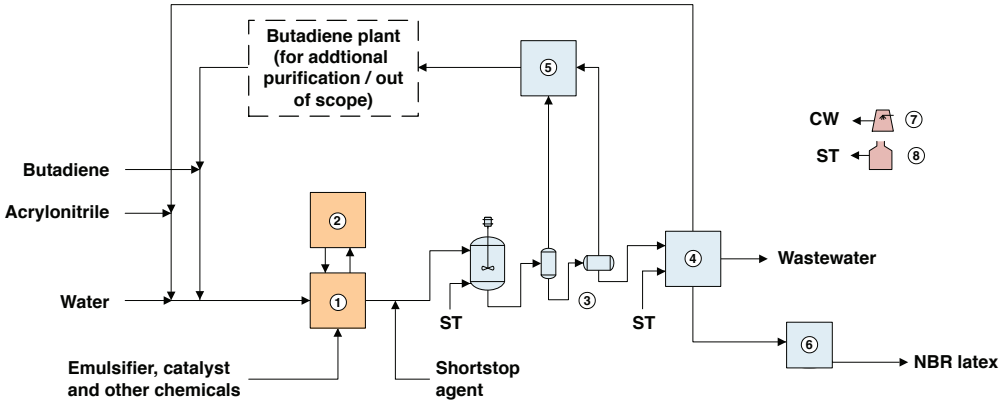


FIGURE 1. The diagram shows a process for the production of acrylonitrile butadiene latex

Understand and Mitigate Waterhammer in Fluid Processes

Waterhammer arises because of sudden changes in fluid flow, and can present significant problems in processes that involve flowing liquids. This article outlines these potential issues and offers guidance for handling the pressure changes arising from waterhammer

Walt Prentice
Applied Flow Technology

IN BRIEF

Most large-scale processes in the chemical process industries (CPI) are designed to run at steady state. Even if a process is a batch operation overall, it usually includes at least some continuous segments. When fluid flows are constant, process operation is efficient, cost-effective and safe, and effects are predictable. However, when fluid flows change (whether the change was intentional or not), a wide range of consequences can result, and they are often difficult to fully comprehend and predict. The effects from changing fluid flow are collectively classified as "waterhammer." This term has also been used in the context of home plumbing systems, where waterhammer can generate noise from otherwise silent pipes. However, waterhammer in home plumbing represents only a small-scale example of what can be very serious topic at industrial scales (Figure 1).

Waterhammer is the phenomenon of pressure-wave propagation that follows a change in fluid flow — usually in the context of a sudden change. It is most common to associate these changes with a valve closure of some sort. Liquid systems running at steady state have large amounts of momentum. In a situation where the momentum of flowing liquid is stopped suddenly, the forward kinetic energy is converted to potential energy, in the form of pressure. Controlling this pressure rise is a salient concern for industrial processes.

As flowing liquid comes to a stop throughout the rest of the pipes, the resulting pressure wave propagates, similar to a sound wave in air. A logical line of consequences follow: moving flow stops, rising pressure results, propagating pressure waves march forth. Propagating pressure waves can cause damage to pumps, to pipe components, and to the pipe itself. As a result, standards and codes have existed for some time to guide engineers toward a safer design.

High-pressure considerations

The American Society of Mechanical Engineers (ASME; New York, N.Y.; www.asme.org) standard B31.4 (Pipeline Transportation Systems for Liquids and Slurries) states that protective equipment must be in place to ensure that any pressure surge does not exceed 10% above the internal design (steady-state) pressure. This stipulation provides a baseline for system design. The process engineer's job then is to analyze those situations and locations within the process where flow can potentially change, such as pumps and valves, and make sure that mitigation equipment is sized properly, according to the possible changing-flow scenarios.

Most engineers will run calculations on the worst-case scenario, often assuming that a valve closure is instantaneous. These calculations will yield an expectedly conservative pressure rise, and engineers can then design the protective equipment, such as bladders or relief valves, to control the surge and meet the requirements of the design code. The standard formula for maximum pressure surge is the Joukowsky equation, as shown in Equation (1).

$$\Delta P = -\rho a \Delta v \quad \textbf{(1)}$$

In the equation, ΔP is the instantaneous change in pressure, ρ is the fluid density, a is

the wave speed (a function of the fluid and pipe properties), and Δv is the instantaneous change in velocity. This equation is valid as long as the implications and assumptions are well understood. Figure 2 shows a pressure surge from a fast valve closure.

The Joukowsky equation describes the pressure rise from an instantaneous change in velocity. That pressure rise will represent the worst-case scenario for components near that valve for the initial pressure wave. But this initial surge will result in secondary effects when waves do what waves do, which is to propagate, reflect and interfere with one another. In long pipelines, there is also line pack (frictional pressure-loss recovery) to consider. Often, these later effects can result in worse conditions than those arising from the initial surge. Predicting these secondary effects by hand is a tall order, but software for waterhammer analysis is available and can be helpful.

FIGURE 1. Changes in fluid flows within industrial piping systems can cause waterhammer, which can result in a wide range of consequences

Low-pressure considerations

One of the major (and often unanticipated) effects of waterhammer is low pressure. It is not the obvious concern, and it is not easily predicted. As mentioned previously, design codes are available for allowable overpressure, but there is not a single code for allowable underpresssure. Engineers are left without guidance in that regard. Many engineers unknowingly consider only half of a pressure wave's effects.

There are many different events that can cause low-pressure waves. One of the more intuitive examples is something like a pump shutdown. As a pump shuts down, pressure is no longer supplied to the fluid, but the fluid still moves forward. This leaves a low-pressure zone that eventually catches up to the rest of the line as it finds mechanical equilibrium.

However, low-pressure effects also arise as part of the wave cycle from the traditional valve closure discussed above. The high-pressure wave travels through the pipe until it meets a point of reflection. When that wave travels back toward the originating valve, it reflects again with a low-pressure wave. This is the second half of the "wave cycle."

Although hard to visualize, the wave cycle follows a momentum balance of velocity and pressure. Without introducing too much detail, velocity also

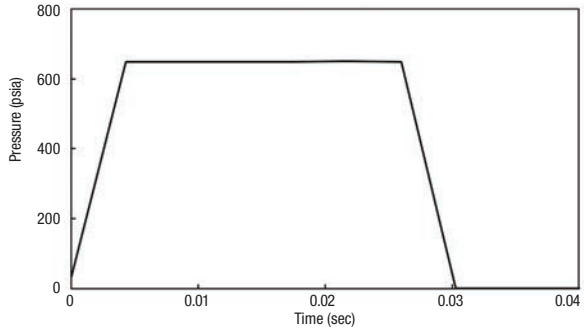


FIGURE 2. The graph depicts a pressure surge following a rapid valve closure in a pipeline

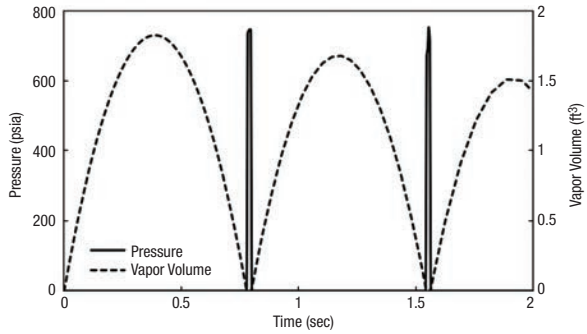


FIGURE 3. After a rapid valve closure, such as the one represented in Figure 2, the pipe can experience a vapor-collapse scenario, as shown here in graphical form

changes as the pressure wave cycles. When the wave reflects off the originating valve, the fluid changes from negative velocity to zero velocity. This "increase" in velocity is met with a decrease in pressure, below the steady-state value. A low-pressure wave will always follow a high-pressure wave. The severity of the low-pressure wave depends on dampening from friction and mitigation efforts.

Another case of low-pressure concern in waterhammer is the area immediately downstream of the closed valve. Similar to the pump trip, there is no momentum transfer to the downstream fluid once that valve has closed, but the fluid still has inertia driving it forward until the system corrects toward equilibrium. This creates a low-pressure area and disturbs the line's pressure balance.

Whatever the cause of low-pressure waves, they are frequently not considered in a transient analysis. Thinking intuitively, one might imagine that the low-pressure situation cannot be nearly as bad as the high-pressure effects. It is common to associate high-pressure scenarios with higher overall pipe stress and lower-pressure occurances with less pipe stress. While that thinking is somewhat true, there are other factors for which to account.

Vapor formation

If the negative-pressure wave drops the line pressure below the vapor pressure of the fluid, the fluid will flash (partially evaporate) and form a short-lived vapor pocket. When the pocket is large enough to form a clear boundary between the upstream and downstream liquid, the situation is referred to as "liquid column separation." This term is also used more generally to describe any liquid flashing.

Formation of vapor pockets inside a pipe can create a situation that is worse than the initial high pressure. Pipes tend to resist internal high pressure much better than they resist internal low pressure. Often, vapor pockets create vacuum conditions where the ambient pressure is much higher than the internal pressure. This pressure differential can actually be more strenuous on a pipe than if the pressures were reversed (higher pressure inside the pipe than outside the pipe). These pressure differences due to these vacuum conditions may cause pipe collapse and harm the integrity of the pipe wall.

Even if the pipe does not collapse, the vapor pocket will. The collapse causes yet another high-pressure wave to burst forth. These resulting pressures can be even larger than the original pressure wave from the valve closure. The vapor pocket collapses with so much power that it often bursts nearby pipe joints. The concept is very similar to pump cavitation. The collapse of the tiny vapor bubbles happens with enough force to cause "pitting" and damage to the impellers. The same thing happens with liquid column separation, but on a larger scale. Figure 3 shows the vapor collapse behavior downstream of the same fast valve closure shown in Figure 2. Compare the resulting pressures here with the initial pressure seen in Figure 3. The large pressure from vapor pocket collapse is not predicted by conventional calculations.

Stress on a pipe and its components due to vacuum conditions and vapor collapse may not be the most critical concern. In many situations, such as wastewater treatment or food processing, the process itself is the concern. Even mild vacuum conditions can pull outside contaminants into the pipes. Joints are the main concern here, because the seals and gaskets will be the

areas where those contaminants come through if a vacuum is present inside the pipe. Engineers working with aseptic processes especially need to be vigilant for these conditions.

Transient event mitigation

Hopefully, the prior sections of this article have made it evident that waterhammer is a serious and complex issue. From a single transient event, a wide range of damaging conditions can arise. So the question now becomes how to mitigate the effects of waterhammer. While the instigating events may be unavoidable, engineers can design countermeasures to account for the effects of waterhammer and maintain compliance with the ASME code.

A common way to mitigate waterhammer is to manage the initiating event itself, if possible. The simplest solution is to close the valve over a longer period. The previously mentioned Joukowsky equation predicts the pressure rise from an instantaneous change in flow. If that change in flow is spread over a longer time, then the resulting pressure wave is less extreme. The longer the time interval for fluid-velocity change, the lower the magnitude of acceleration, and the lower the resulting force and pressure.

Like most of life, the reality is more complicated. Each type of valve has unique characteristics, and the exact timing of how to close the valve depends on those characteristics. The suggestion for valve closure mainly relies on how the C_V (flow coefficient) changes with valve position, and then how that valve position changes over time. If C_V (and thus, flow) changes dramatically near the end of valve closure, it is very important to close it slowly during that period.

There is a common valve closure practice known as the "80/20 rule." That is, take 20% of the total valve-closure time to close the first 80% of the valve, and then take the last 80% of the time to close the final 20% of the valve. Closing the valve more slowly toward the end mitigates the surge because this is usually the moment of largest velocity change.

However, even this rule of thumb has its limitations. If the valve has a large pressure drop relative to the pressure drop of the entire system, then this valve may already have tight control of the flow. Changing the valve position affects the system's flow significantly. In this case, the valve should be closed very slowly throughout the entire closure, because every change in position is significant. Understanding your valves and their interaction with the system is important, but difficult. Software for waterhammer analysis can be helpful in this regard as well.

Surge suppression equipment

Slowing valve closures as a waterhammer-mitigation method require a planned closure. But of course, an unplanned need to close a valve can also occur, leading to unexpected transient flow events. For instance, a power outage may cause a pump trip, which then causes a check valve slam (rapid closure). In cases like these, in-line equipment is required to mitigate the waterhammer.

Relief valves or rupture disks are common in-line components, because they are a logical resolution to high-pressure

FIGURE 4. Closed surge vessels filled with inert gases, such as the one shown here, can be used as waterhammer-mitigation devices

situations. Similar to a crumple zone in a car, relief components take the load on themselves. They pop open when pressures become too high, easing the effects on other parts of the process. Unfortunately, rupture disks and relief valves are not all-encompassing solutions, because they are sized for certain pressure scenarios that are not always easily predictable.

Vacuum-breaker valves are another mitigation strategy with the opposite motive of relief valves. For the low-pressure situations discussed earlier, the vacuum-breaker valves break the vacuum that can accompany a low-pressure condition (where the pipeline pressure is below ambient pressure). Vacuum-breaker valves allow air into the system to relieve the low pressure.

That same breaker valve may also have a way for the air to escape when the pressure bounces back. With these multi-stage valves, the exit rate is very important to control. If the air leaves too quickly, the fluid columns may slam together, causing yet another surge event. While breaker valves are effective, they may not be practical if a process is sensitive to contamination or oxidation. An inherent limitation of single-stage breaker valves is that the trapped air will cause a decreased area for liquid flow, and thus, will increase the fluid's velocity. Additionally, the entrained air can negatively affect pumps and other components.

In addition to valves designed to relieve either high or low pressures, there are surge vessels that mitigate both extremes. Surge vessels come in many styles, but they are essentially in-line vessels that provide both a refuge and supply for process fluid during a transient waterhammer event. Two standard styles are open and closed vessels. Open vessels are also known as "standpipes," and are useful when contamination is of little concern. Closed vessels are charged with an inert gas to control the compression and expansion (Figure 4).

When surge pressures arise, the vessels absorb the energy from the pressure spike, acting as an energy sink. When the low-pressure part of the wave cycle comes through, the vessels become an energy source, providing the necessary fluid and pressure. In this way, they act like both relief and vacuum-breaker valves, but they are much more versatile. Closed vessels act for both the high and low pressures, while open vessels are typically designed for protection from low-pressure situations. The nature of open vessels requires excessively tall walls if the vessel is intended to absorb a high-pressure surge. However, this is not unheard of.

Waterhammer analysis software

The ability to predict the placement of waterhammer-mitigation components is no easy task. The design of the mitigation components themselves also requires the pressure predictions discussed earlier. Incorrect placement of this equipment can make the situation even worse, through resonance or re-triggering the surge. But most engineers work in aging plants, so they inherit the system of the original designers. Plants usually have relief valves or vessels distributed throughout. For plants designed decades ago, without modeling software, introducing relief valves and surge vessels was a common practice to protect against unpredictable surges.

Without software to analyze wave behavior, process design becomes a rough estimate in an effort to meet the requirements of the code. Modern modeling methods allow engineers to better predict waterhammer events and the effectiveness of mitigation efforts. Targeted pressure control makes processes safer and more efficient overall. But more robust mitigation efforts require more robust technology for guidance. Being able to predict the unanticipated low pressures, column separation and subsequent high-pressure waves requires more time and calculation than most engineers are willing and able to invest. After all, the system is probably designed for steady-state conditions.

Waterhammer analysis software can take the pressure off engineers by modeling the transient events, predicting expected behavior at various conditions, and evaluating the effectiveness of suppression methods. Even today, waterhammer analysis is not always part of the standard design process. Using the initially assumed worst-case scenario is often where the analysis starts and stops. Instead, take waterhammer analysis beyond the standard methods, and consider all the complex consequences of a change in flow. ■

Edited by Scott Jenkins

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Sealing Technology for Caustic Service

This overview compares various sealing technologies, and points out advantages and disadvantages of applying different mechanical-sealing designs for caustic fluids

Brian Kalfrin
John Crane Inc.

IN BRIEF

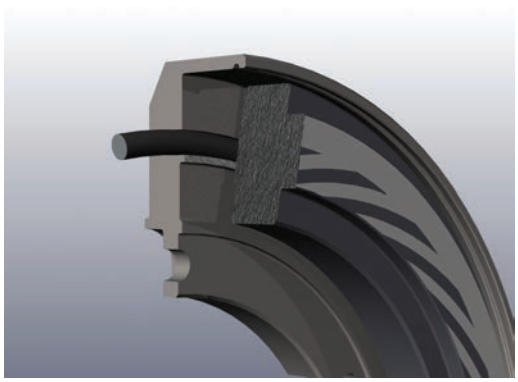
Caustic applications in chemical plants can play havoc on the mechanical seals of rotating equipment. These applications can be difficult to seal because of the caustic chemical properties in both solution and dehydrated states. Caustic solutions form harmful crystals as the liquid evaporates and the concentration increases past the solubility point. As the solution becomes hotter or more concentrated (or both), it becomes more corrosive, further impacting mechanical seal reliability.

Each caustic application presents unique complications due to different concentrations, desired purity levels and pump design. As a result, seal manufacturers have developed seal designs and support systems to ensure that the seal will survive the harsh demands placed on them by the pump, the process and the operating conditions. Among these new seal designs is the dynamic lift up-stream pumping (USP) technology.

Understanding these seal design options and arrangements for caustic applications, along with their benefits and shortcomings, will help chemical operations avoid costly mechanical failures, equipment damage, impacts to the environment and personnel exposure to hazardous materials.

An overview of sealing technologies

Single seals. Single seals, defined in API 682 "Pumps — Shaft Sealing Systems for Centrifugal and Rotary Pumps" as Arrangement 1 (Figure 1), are the simplest and least expensive method of achieving a seal for any pump. The mechanical seal faces are lubricated by the process fluid. In the case of applications such as caustic, normal seal leakage across the seal faces can result in plating and atmospheric side deposits that can contribute to seal component hang-up. For this reason, conventional piping plans, such as API Plan 11 are less desirable in these services.



For sealing caustic applications, an API 682 Plan 32 flush is often recommended. This system injects clean liquid from an external source into the seal chamber (also known as the stuffing box) at a pressure slightly higher than the chamber itself. Because the external fluid flow needs to be high enough to prevent ingress of the caustic fluid, the costs associated with the flush can prove prohibitive.

Dual unpressurized seals. Dual unpressurized seals defined in API 682 as Arrangement 2 (Figure 2), utilize an unpressurized buffer fluid between two pairs of seal faces. The inner seal faces are lubricated by the process fluid. Any leakage across the inner seal is added to the buffer fluid.

In caustic applications, this arrangement leads to contamination of the buffer fluid from inner seal leakage. To combat this, an API Plan 32 is recommended for a dual unpressurized seal, with the same drawbacks as a single seal for added fluid initial expenditure, but with the additional costs of circulating another fluid and the associated support system cost, monitoring, and maintenance requirements.

Dual pressurized seals. Dual pressurized seals defined in API 682 as Arrangement 3 (Figure 3), utilize a barrier fluid pressurized above the process pressure. The seal faces are lubricated by a clean barrier

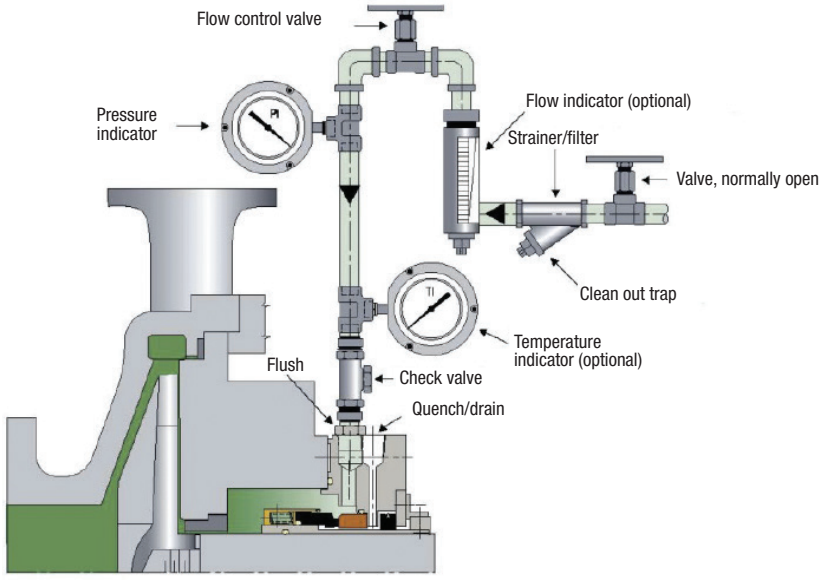


FIGURE 1. A typical API Flush Plan 32 is diagrammed here

fluid. Any leakage across the inner seal face will therefore be from the barrier fluid into the process fluid.

Because the leakage across the inner seal faces is clean barrier fluid, abrasive particles from the caustic fluid are isolated from the seal face area.

The initial cost of this option is the most expensive, due to the complications of providing a pressurized barrier-fluid system. However, this option generally offers better reliability than the other two arrangements since seal performance is not dependent on the process fluid for lubrication.

Dynamic-lift USP technology

A conventional mechanical seal operates by utilizing the higher pressure fluid as a film between two precision-lapped seal faces. The hydrodynamic action of the seal allows a film to form of usually less than 1 μm that lubricates, cools and minimizes mechanical contact. Any leakage across the seal faces occurs from a higher pressure fluid into a lower pressure region.

How it works. Dynamic lift technology uses grooves on one of the seal faces to generate pressure between the seal rings so that they physically separate and operate in non-contacting mode (Figures 4 and 5). The most well-known use of this is for dry gas seals, where a barrier gas at a higher pressure than the sealed pressure is used to separate the faces.

Dynamic lift USP utilizes specially optimized spiral grooves on one of the seal faces to create a pumping effect. The face design generates a positive pressure across the seal face from inside diameter to outside diameter — that is, from the lower-pressure buffer fluid to the higher-pressure process fluid in the seal chamber. This has the effect of raising the pressure of the fluid film between the seal faces to above that of the process (Figure 5). The pumping mechanism creates a controlled flow of buffer fluid from low-pressure into the higher-pressure process fluid. The seal acts like a pressurized dual seal without the need to pressurize a barrier fluid. The low-pressure buffer fluid is sealed by a containment seal typically operating at the preset buffer-fluid pressure, but capable of containing the seal chamber pressure in the event of an inner seal failure.

Advantages. Dynamic-lift up-stream pumping technology offers many advantages over the traditional dual-seal approach, including the following:

- The technology is "non-contacting" and therefore the usual pressure-velocity limitations imposed by contacting seals, and the resultant wear, do not apply
- The power consumed is significantly lower than a dual-pressurized or unpressurized seal arrangement
- Compared to a dual unpressurized seal, a USP seal has the advantages of clean fluid lubrication and non-contacting operation
- Compared to a dual unpressurized seal, a USP seal requires a much simpler support system
- The process fluid is on the outside diameter of the seal faces — solids suspended in the process fluid are centrifuged away from the seal faces and secondary seal area
- Buffer fluid leakage to atmosphere is significantly reduced when compared to a pressurized dual seal, where the outer seal can often operate with a considerable pressure differential
- The concept allows a simple upgrade of single- or multiple-seal services where process changes have rendered the process fluid a poor seal lubricant
- In services where the process pressure is variable, or where pres-

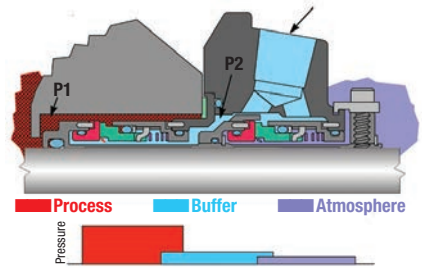


FIGURE 2. Shown here is a typical dual unpressurized seal pressure arrangement

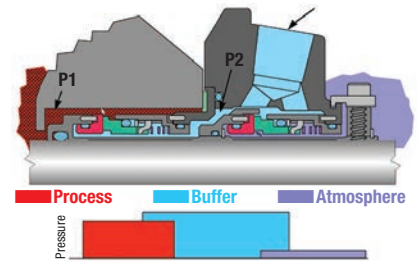


FIGURE 3. This diagram shows a typical dual pressurized seal arrangement

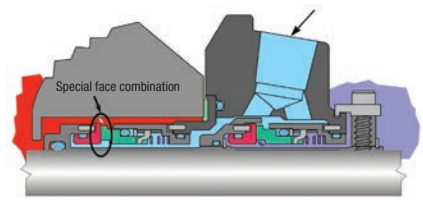


FIGURE 4. A typical up-stream pumping arrangement is shown here

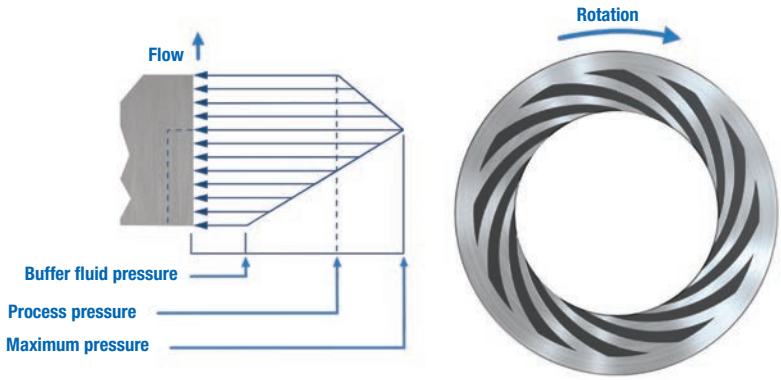


FIGURE 5. This diagram shows the pressure generation in a USP seal

sure spikes are likely, the spiral groove constantly regulates against this varying pressure, maintaining a sealing gap at all times

- The flush requirement for dual pressurized or unpressurized arrangements is often unnecessary with USP due to low heat generation, reducing water usage
- Increased mean time between repair (MTBR)

Developing the high-pressure USP seal. The first high-pressure USP seal was designed and validated back in 2003. The initial design focused on an emulsification of oil and water contaminated with varying concentrations of sand.

The 75-mm seal design shown in Figure 6 was tested under the following operating conditions:

- Shaft speed: 3,600 rpm
- Seal chamber pressure: 5 to 40 barg
- Seal chamber temperature: 70–80°C

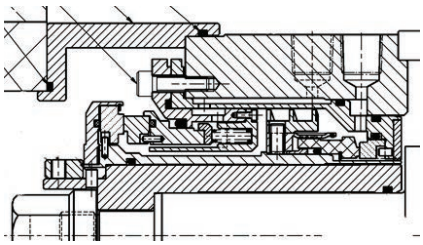


FIGURE 6. This cutaway shows the first high-pressure USP sealing arrangement

- Process fluid: water, water/oil/sand (20 wt.% sand)
- Buffer fluid: seawater

Simplified seal-support systems. By nature of the design and operation of dynamic-lift USP mechanical seals, the required support system complexity is greatly reduced compared to that used with a conventional dual pressurized seal.

For example, due to a lack of cooling requirement for many designs, the system requirement is simply an elevated tank with an optional automatic fluid top-up

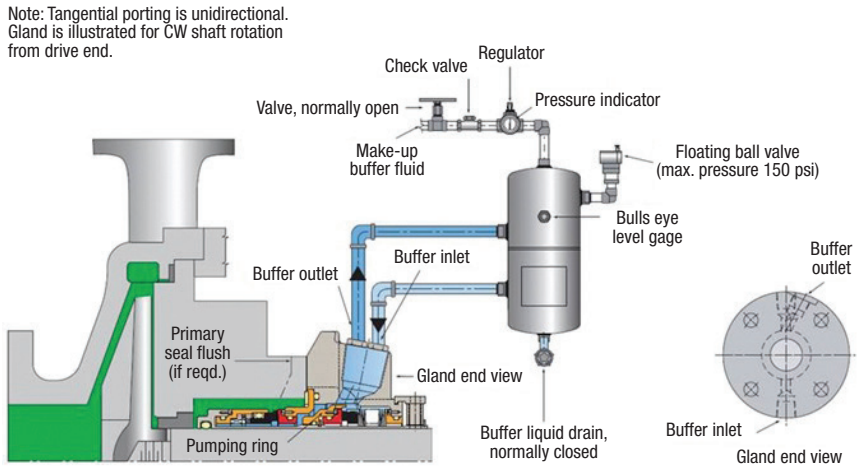


FIGURE 7. This schematic shows a typical piping plan arrangement

system. Figures 7 and 8 show examples of a basic support system.

Two case studies

This final section presents two applications of the mechanical seal using dynamic-lift technology.

Case 1. Improving MTBR at a chemical plant. Recently, a chemical plant in the eastern U.S. experienced a high seal-failure rate on one of its proprietary single-pump processes. Over the course of one year, the traditional mechanical seal required repair or replacement at least 17 times.

The toll plant, specializing in intermediates, polymers and colorants used by a diverse customer base around the world, relied primarily on a manual operation, leading to repeated production errors. The low seal mean time between repair (MTBR) hit the company's bottom line in production and maintenance costs.

A thorough review of the operation and a comprehensive failure analysis revealed that employees would manually dump improper levels of crystal particles into a conical-bottom process tank. Because there was no way to measure the proper particle-to-water ratio — only employee judgment — incorrect levels were applied, often in chunks. As the volatile mixture recirculated in the tank, the seal and pump would not only starve at the start, but would also deadhead at the end of the process. This caused the seal to overheat and cook the O-rings until they resembled "charcoal." Engineers consided a proven recirculating seal-support-system technology that would accommodate the manual process.

FIGURE 8. A typical piping plan arrangement with a USP seal in operation

After the pump was rebuilt, the plant agreed to a six-month trial that replaced the existing mechanical seal with a 1.750-in. T5620 USP seal. The seal was chosen for the operation because it is designed to handle the inconsistent and caustic mixtures of the plant's manual-dissolution process. Inboard seal faces, comprised of silicon carbide material, combined with the dynamic-lift USP face pattern.

Following the six-month trial, plant engineers said they "were ecstatic" with the performance of the T5620 USP seal. The USP seal racked up an impressive three-year MTBR, a significant improvement over the previous MTBR performance. Immediately following the installation of the USP seal, the plant eliminated the frequent half-day production interruptions, saving the company untold sales revenue. Pulling technicians away from other duties, oftentimes for four to six hours to work on the pump and seal, came to an end. The plant saved nearly $25,000 in seal-repair costs over three years after the USP was installed.

Case 2: Saving water at a chemical-processing plant. Engineers at a large chemical manufacturing plant on the east coast of the U.S. were concerned about how much water it used to process lithium hydroxide. Packing on a water pump used in the process caused significant water loss, requiring constant adjustments by plant technicians.

When the water/lithium hydroxide slurry seeped into the red clay under the plant, the reaction caused significant concrete floor heaves. The U.S. Environmental Protection Agency (EPA; www.epa.gov) required the plant to curtail the water and lithium hydroxide losses and adhere to regulations. The 24/7 chemical-manufacturing plant needed a cost-effective solution to stop the leakage to reduce costs, stop damage to the floor and conform to EPA requirements.

The company sought a solution to the problem on an open-vane, recirculating propeller pump. After careful review, it was determined that the lithium-hydroxide process was losing nearly 1.8-million gallons of water annually. Because of the water leakage, the plant's floor would heave approximately 1.25 in./yr at the site of the process. Some areas of the floor rose 6 in. higher than other spots, creating trip hazards and costly pump, piping and infrastructure adjustments. Because of the thick and volatile nature of the slurry, traditional seals had not worked to correct the problem in the past.

Plant engineers agreed to discard the existing pump packing and replace it with engineered USP noncontacting face and filtered water-buffer-fluid seal technology. The pump was reconditioned and a 2-in. T5620 USP seal standard double-seal was installed.

The USP seal performed for six years of uninterrupted operation, eliminating constant attention from plant service personnel to service the pump packing. Annual planned packing replacement was eliminated. Excessive water consumption and associated costs were immediately halted, allowing the plant to cut water usage by up to 1.8 million gal/yr. EPA concerns regarding the water leakage into the clay soil were addressed. Leaks into the ground from the lithium-hydroxide process no longer caused the floor to heave. ■

Edited by Gerald Ondrey

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Like Metals, Polymers Fail — but Differently

This pictorial guide illustrates some of the common problems that can occur with polymeric and elastomeric materials that differ from those that occur with metallic seals and components

Ana Benz
IRISNDT

IN BRIEF

Failures of polymer (plastic and elastomeric) parts and their consequences can be as significant as those of metallic equipment. The information presented introduces some characteristics of polymer parts that impact the equipment that is used at industrial sites. The information covers some aged O-rings, lined pipe, fiber-reinforced plastic (FRP), and pipelines with liners. Characteristics such as permeation, glass temperature, and viscoelasticity are discussed, along with examples of their consequences.

Background

The Space Shuttle Challenger disaster on January 28, 1986, shocked the world. The explosion was due to the O-rings not being able to seal.

The malfunctions described in this article introduce some characteristics of nonmetallic failures that impact equipment used at industrial sites. For each case, important polymer properties are discussed.

Elastomer O-ring failures

Elastomers have glass transition temperatures, which are defined as "the temperature at which an amorphous material (such as glass or a polymer) changes from a brittle vitreous state to a plastic state" [*1*].

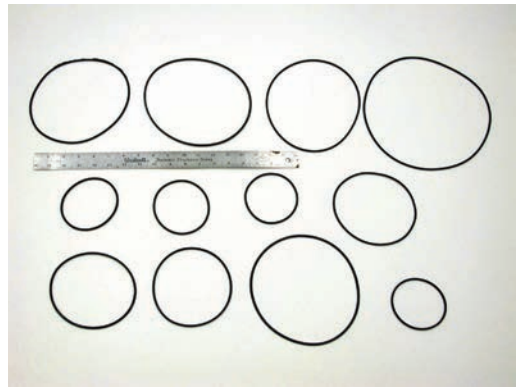

FIGURE 1. Shown here are O-rings after being used in steam service

Elastomers have a compression set — this is "reported as the percent of deflection by which the elastomer fails to recover after a fixed time under specified squeeze and temperature" [*2*]. In the author's words, the compression set is the rubber's ability to spring back to its original shape. In many services, the compression set is offset by some of the swelling that develops in service. However, as exemplified below, this is not always the case.

Failure 1. The low 36ºF ambient temperature before launching resulted in the Challenger Space Shuttle's Viton O-rings being inadequate. As stated in various accident investigations, "Below 50°F, Viton V747-75 O-rings were insufficiently resilient to track the test gap opening" [*3*]. The glass transition temperature resulted in the Challenger O-rings not being able to seal.

This property impacts seals during low-temperature start-ups — even flare stacks.

Failure 2. The seals shown in Figures 1 and 2 were exposed mainly to water and steam. The site from which the seals were taken had been using ethylene propylene diene terpolymer (EPDM). However, they were testing fluoroelastomer (FKM), such as Viton) and perfluoroelastomer (FFKM), such as Kalrez O-rings. Despite the differences in size, all of the O-rings shown in Figure 2 initially were of the same size:

- The EPDM retained its shape
- The FKM developed an extensive compression set — it did not spring back and may not have sealed the gap between metallic parts when the operating conditions changed
- The FFKM stopped being round, and it also expanded significantly. The expansion of the perfluoroelastomer resulted in parts of the O-ring protruding from their seat. The protrusion, in turn, resulted in the damage shown in Figure 3.

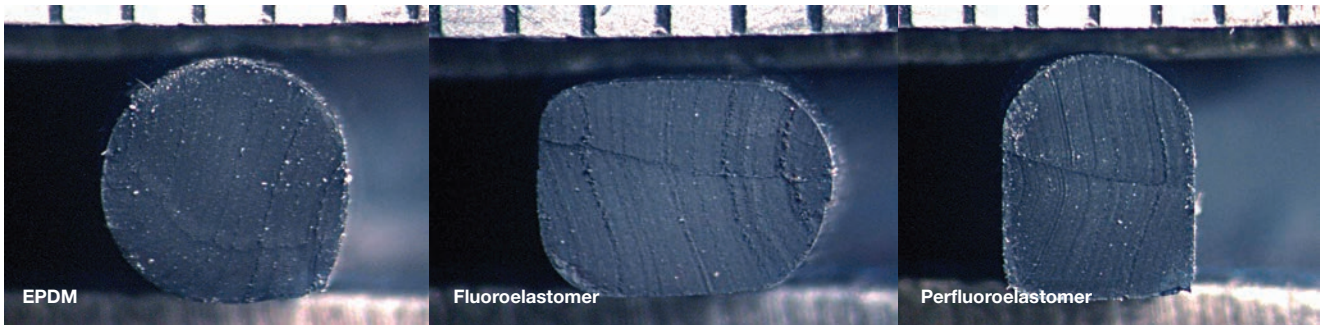

FIGURE 2. These images show cross sections of O-rings after being used in steam service

FIGURE 3. This perfluoroelastomer suffered damage after steam service

What happened? Steam service is challenging for elastomers. For steam service at temperatures greater than 250°F, gland design calculations considering the expansion of FKM and FFKM and their compression set are needed. Various elastomers have specific advantages and disadvantages — even those with high chemical resistance. Any change requires meticulous care.

General notes on elastomers. In general, for elastomers, service at temperatures greater than 250°F and temperatures below 35°F is specialized, and may require a designer's input.

Identifying the elastomer compounds used is important. Fourier-transform infrared spectroscopy (FTIR) allows one to distinguish between significantly different types of elastomers, such as the EPDM, FKM and FFKM described above. However, examinations to differentiate between one FKM compound and another can be challenging. O-rings made by different manufacturers can have different fillers, curing and processing. All of these have significant effects on the compres-

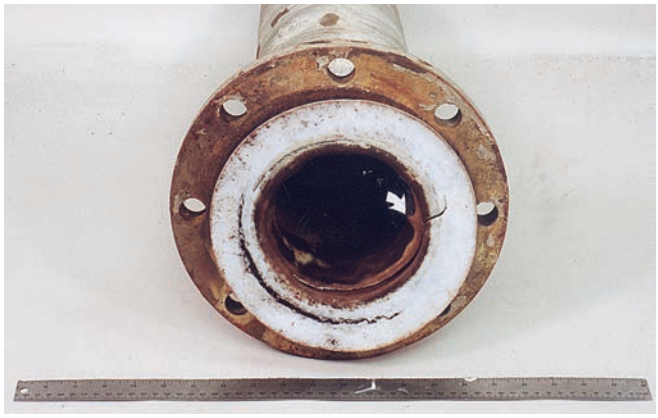

FIGURE 4. A failed Teflon-lined pipe is shown here after more than 10 years of HCl service

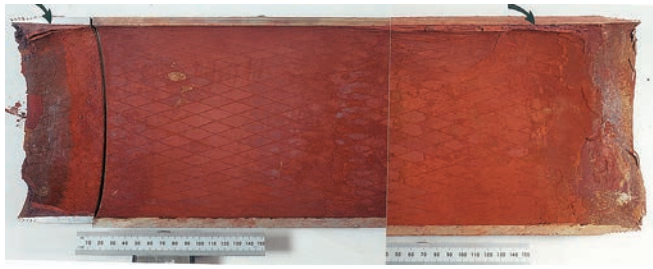

FIGURE 5. Shown here is the steel surrounding the failed Teflon-lined pipe of Figure 4

FIGURE 6. This photo shows an HDPE liner that has collapsed

sion set, chemical resistance and low-temperature performance.

Lined-pipe failures

Polymers have long repeating chains of molecules, which allow some fluids to permeate through them. Unlike metals with their crystalline structures, the long molecules become entangled with each other, much like a single strand of cooked spaghetti. Physically very small molecules, such as water/water vapor and gases, can permeate. Some molecules are sufficiently small to pass through the gaps between individual chains.

Failure 3. Typically, the documentation of a failure-analysis investigation starts with images of the parts as received. However, a flat, pliable gasoline-reeking piece of plastic received on a Friday had altered by Monday (when the photos were to be taken) into a rigid and round piece of pipe. Reportedly, the part had been a polyethylene (PE) pipe sheath protecting electrical components below the ground level in a gasoline station. The flat pliable piece of plastic received could not have protected the cables. Gasoline permeation had resulted in a physical, not a chemical change — the PE pipe had not degraded. Nevertheless, a pipe with less permeation softening was needed.

Failure 4. Many industrial sites use Teflon-lined steel pipe for water processing, acid processing, and applications where metal contaminants cannot be present (such as in the food industry). Teflon-lined pipe has vents that allow permeated water on the annular space between the steel and the liner to exit. Nevertheless, after long service periods, the lined pipe has a "best before date."

Figure 4 shows a Teflon-lined pipe used in HCl service for more than ten years. Voluminous steel-corrosion products had accumulated in the annular space between the liner and the steel pipe. The products pushed the liner inward, causing damage, as shown in Figure 5. Steel corrosion continued until the pipe leaked.

Also, the flanged Teflon surfaces had been subjected to creep. Creep is defined as strain (distortion) under constant load. As is the case with metals, creep in polymers increases with increasing temperature. However, unlike steel, creep occurs at room temperature. Likely, as the flanged surfaces' cross-section had decreased, the steel pipe bolts were retightened until the circular crack shown in the photos developed. The circular crack further exposed the steel pipe to HCl.

Failure 5. The upstream oil-and-gas industry uses high-density polyethylene (HDPE) liners commonly to refurbish pitted steel water-injection lines. However, the depressurization of liners has specific management requirements. Figures 6 and 7 show failed liners. The liner single-lobe damage develops as the annular pressure becomes greater than the internal service pressure — the liners collapse due to permeation. For HDPE liners, the best measure to prevent this failure is to avoid rapidly depressurizing the lines.

FRP failure due to cyclic service

The strength of FRP parts is reduced by cyclic service. As service progresses, the multiple layers can delaminate and crack. API 15 HR, "High-pressure Fiberglass Line Pipe," has a statement about 20% pressure variations being a limit for testing and service. Canadian standard CSA Z662 "Oil and gas pipeline systems" Clause 13.1.2.8, states that pressure swings need

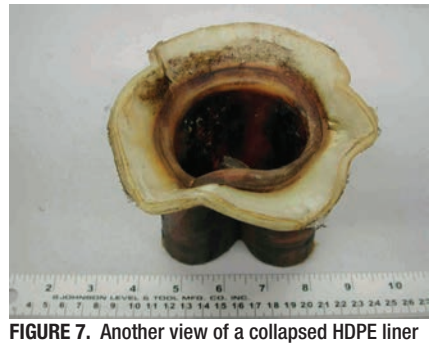

FIGURE 7. Another view of a collapsed HDPE liner is shown here

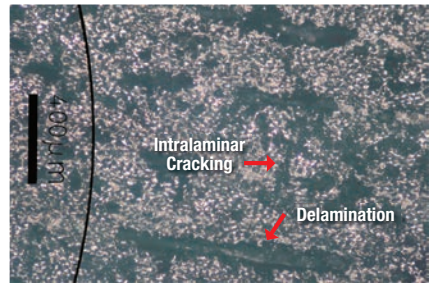

FIGURE 8. This is a transverse cross-section of failed fiberglass in HDPE-lined fiberglass pipe.

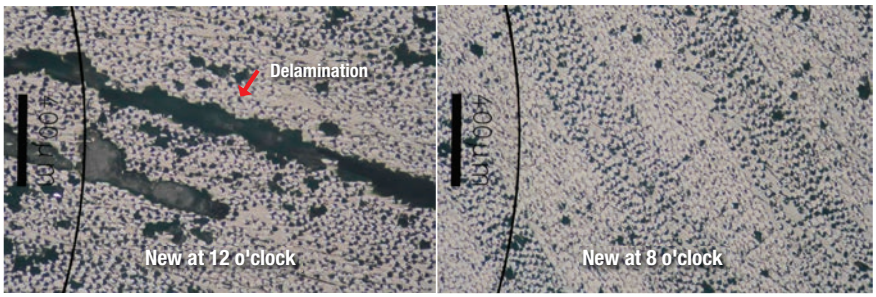

FIGURE 9. Here are two additional transverse cross-sections of as-fabricated fiberglass in HDPE-lined fiberglass pipe

FIGURE 10. Shown here are the inside (left) and outside (right) surfaces of a joint between FRP pipe sections

to be kept below 20% of the pipe manufacturer's pressure rating. Otherwise, the design pressure can be reduced by up to 50%. Lined FRP and FRP requires cyclic loading to be considered during design.

Failure 6. A fiberglass (FRP) pipe used in saltwater service was lined with HDPE along its bottom (6 o'clock) side. The failed section, a non-failed section downstream of the failure, and a third piece (representing an as-fabricated piece) were examined. Specifically, transverse cross-sections of the failed area were compared to those of an as-fabricated pipe of the same size (see Figures 8 and 9). Note the extensive intralaminar cracking in the failed cross-section in contrast to its absence in the as-fabricated pipe. Both the new and failed pipe had delaminations. Delaminations are common in FRP with high glass content; the high glass content confers higher strengths. The pipe had been subjected to severe pressure swings (greater than 20%), and it failed due to cyclic loading.

FRP installation errors

During site installation, smaller sections of pipe are joined — these joints are critical. Typically, two pipe sections are butted against each other, and the gap between the pipe is filled with a "putty." Then, the joint is wrapped with wide multiple plies of FRP reinforcement saturated with resin. The joint must have adequate reinforcement coverage along the outside surfaces.

Nonmetallic materials, such as the liner and FRP, are viscoelastic. While the characteristic can be challenging to explain, its evidence is common to find — often, damage is introduced during installation, but the leak does not develop immediately. *"Viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation. Viscous materials, like honey, resist shear flow and strain linearly with time when a stress is applied. Elastic materials (such as steel) strain instantaneously when stretched and just as quickly return to their original state once the stress is removed. Viscoelastic materials have elements of both of these properties and, as such, exhibit time-dependent strain. Whereas elasticity is usually the result of bond stretching along crystallographic planes in an ordered solid, viscosity is the result of the diffusion of atoms or molecules inside an amorphous material"* [4].

FRP and plastic parts require exceptional care during installation and handling. Otherwise, they can crack, and the damage may not be evident until much after a hydrotest.

Most lined FRP failures develop because of installation damage [5]. Hydrostatic tests are essential but may not detect small damage that can grow in service.

Failure 7. Figure 10 shows a joint between two FRP pipe sections. Figure 11 shows a cross-section of the joint. The external reinforcement and coverage along the pipe were insufficient, and the pipe cracked during handling. Guidelines for the reinforcements of joints are given in DIN 16966, CSA Z662, and ASME NM.2.

Slow crack growth in HDPE pipe

HDPE piping is light-weight, corro-

FIGURE 11. A cross section of a joint between FRP pipe sections is shown here

FIGURE 12. In this photo, one can see the intersection from a tee branch to the main run, which developed the crack pointed at with a red arrow

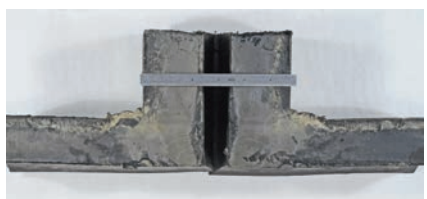

FIGURE 13. This cutaway shows the fracture surface of the tee branch to tee main run

FIGURE 14. A closer view of the fracture surface of the tee branch to tee main run is seen here. Crack initiation is apparent on the inside surface

FIGURE 15. Shown here is a typical storage intermediate-bulk container

FIGURE 16. These cable sheaths have been damaged due to exposure to ultraviolet radiation and aging

sion-resistant, and it is commonly used to fabricate gas mains and water lines — including fire water lines at plant sites. Most failures of these lines are due to excavation damage [*6*]. However, slow crack growth (SCG) failures also develop at relatively low stresses and with minimal deformation. Reportedly, "SCG is a common failure mode in underground polyethylene (PE) piping that was designed for 50-year services" [*7*].

Failure 8. A fire water line developed SCG after more than 20 years of service. Its fracture had the following characteristics:

- Developed where a tee branch intersected the main run
- Had concentric parallel and rachet marks radiating from the inner diameter (ID) surface

The fracture appearance was characteristic of SCG failures — it had minimal deformation and an origin with multiple concentric rings. Once the SCG region grew to ~2 in. by 1.5 in., rapid crack growth with less visible macroscopic features ensued (Figures 12 to 14). The line had been exposed weekly to load variations greater than 10%. Reportedly, newer HDPE compounds are more resistant to failure due to load fluctuations than the older ones [*8*]. Nevertheless, operating plants should consider the potential for SCG as HDPE fire water lines age.

Handling of HDPE containers

Intermediate bulk containers (IBCs) are practical for storing and shipping small amounts of chemicals (Figure 15). They are so dependable that it is easy to forget that their failures pose significant hazards. However, IBC failures can result in significant economic losses — the author has investigated a couple of them. Most of the failures result from mishandling [*9–11*]. While IBCs appear to be simple to examine, HDPE cracks from mishandling can be difficult to see. For the asset management personnel in companies that use IBCs containing hazardous products routinely, careful periodic external and internal inspections are necessary — they are mandatory in the U.S.

UV exposure damage and aging

Ultraviolet (UV) damage and aging are ubiquitous in polymers. This means that we must carefully follow O-ring storage instructions and consider the life implications for outdoor components such as liners of open-top tanks and ponds. While we need to optimize (minimize) maintenance budgets, some inspections are necessary in outdoor components, especially those exposed to sunlight (Figure 16).

Final remarks

Characteristics such as the glass transition temperature, compression set, permeation, creep at room temperature, viscoelasticity, slow crack growth, and others determine plastic and elastomeric parts' service performance. For critical components, these characteristics must be considered to obtain an efficient and effective service for which polymers should be known. ■

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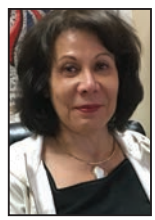

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Economic Indicators

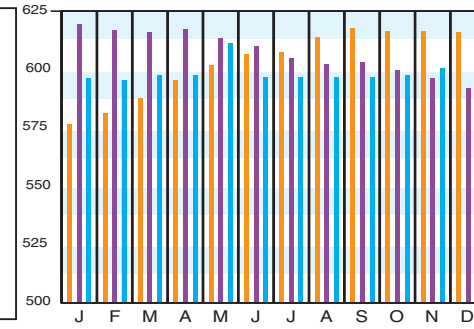
2018 2019 2020 2021

Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Dec. '20 Prelim.	Nov. '20 Final	Dec. '19 Final
CE Index	607.0	600.2	592.1
Equipment	737.4	728.1	716.9
Heat exchangers & tanks	621.4	614.8	611.0
Process machinery	738.1	724.6	714.5
Pipe, valves & fittings	998.7	979.2	951.1
Process instruments	433.4	423.2	419.0
Pumps & compressors	1086.2	1084.0	1075.8
Electrical equipment	571.2	569.5	561.9
Structural supports & misc.	772.5	768.5	750.2
Construction labor	336.8	336.4	338.5
Buildings	621.3	612.7	585.7
Engineering & supervision	311.6	309.6	312.7

Annual Index:
2012 = 584.6
2013 = 567.3
2014 = 576.1
2015 = 556.8
2016 = 541.7
2017 = 567.5
2018 = 603.1
2019 = 607.5

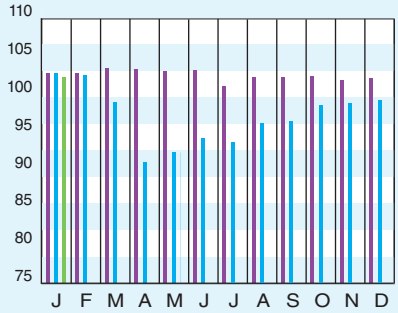


Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

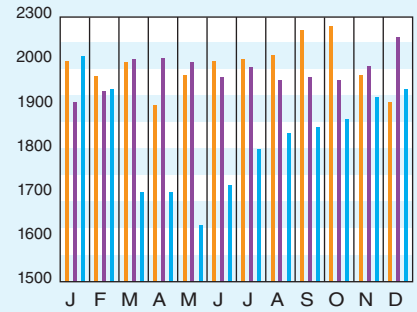
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS		YEAR AGO
CPI output index (2012 = 100)	Jan. '21 = 101.4	Dec. '20 = 100.4	Nov. '20 = 99.3	Jan. '20 = 103.4
CPI value of output, $ billions	Dec. '20 = 1,940.4	Nov. '20 = 1,895.0	Oct. '20 = 1,860.7	Dec. '19 = 2,051.8
CPI operating rate, %	Jan. '21 = 75.8	Dec. '20 = 75.1	Nov. '20 = 74.2	Jan. '20 = 76.9
Producer prices, industrial chemicals (1982 = 100)	Jan. '21 = 250.9	Dec. '20 = 235.3	Nov. '20 = 228.4	Jan. '20 = 246.3
Industrial Production in Manufacturing (2012 =100)*	Jan. '21 = 103.9	Dec. '20 = 102.8	Nov. '20 = 101.9	Jan. '20 = 105.0
Hourly earnings index, chemical & allied products (1992 = 100)	Jan. '21 = 193.8	Dec. '20 = 194.5	Nov. '20 = 189.5	Jan. '20 = 188.2
Productivity index, chemicals & allied products (1992 = 100)	Jan. '21 = 105.5	Dec. '20 = 104.2	Nov. '20 = 104.1	Jan. '20 = 98.7

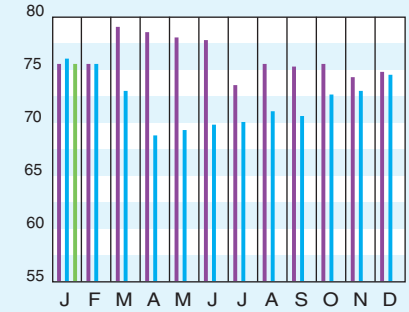
CPI OUTPUT INDEX (2000 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2000 to 2012
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top) for December 2020 (the most recent available) shows a pronounced increase from the previous month's value. The current increase is the third consecutive monthly increase, although the November value was downwardly revised from its own preliminary version. All four of the major subindices saw upticks in the December data. The current CEPCI value now sits at 2.5% higher than the corresponding value from December 2019. Meanwhile, the Current Business Indicators (middle) showed increases in the CPI Output Index for January 2021, as well as the CPI Value of Output for December of last year. The CPI Operating Rate was also up in January.